

FORM PTO-1300
(Rev. 3-93)

U.S. DEPARTMENT OF COMMERCE PATENT AND TRADEMARK OFFICE

Attorney's Docket Number **0819-383**

**TRANSMITTAL LETTER TO THE UNITED STATES
DESIGNATED/ELECTED OFFICE (DO/EO/US)
CONCERNING A FILING UNDER 35 U.S.C. 371**

U.S. APPLICATION NO. (If known, see 37 CFR 1.5)

09/554599INTERNATIONAL APPLICATION NO.
PCT/JP98/05311INTERNATIONAL FILING DATE
November 25, 1998PRIORITY DATE CLAIMED
November 26, 1997

TITLE OF INVENTION

FIBER GRATING AND METHOD AND APPARATUS FOR FABRICATING THE SAME

APPLICANT(S) FOR DO/EO/US


Kazuo IMAMURA, Tadahiko NAKAI, Yasuhide SUDO

Applicant herewith submits to the United States Designated/Elected Office (DO/EO/US) the following items and other information:

1. ☒ This is a **FIRST** submission of items concerning a filing under 35 U.S.C. 371.
2. ☐ This is a **SECOND** or **SUBSEQUENT** submission of items concerning a filing under 35 U.S.C. 371.
3. ☒ This express request to begin national examination procedures (35 U.S.C. 371(f) at any time rather than delay examination until the expiration of the applicable time limit set in 35 U.S.C. 371(b) and PCT Articles 22 and 39(1).
4. ☒ A proper Demand for International Preliminary Examination was made by the 19th month from the earliest claimed priority date.
5. ☒ A copy of the International Application as filed (35 U.S.C. 371(c)(2))
 - a. ☐ is transmitted herewith (required only if not transmitted by the International Bureau).
 - b. ☒ has been transmitted by the International Bureau.
 - c. ☐ is not required, as the application was filed in the United States Receiving Office (RO/US).
6. ☒ A translation of the International Application into English (35 U.S.C. 371(c)(2)).
7. ☒ Amendments to the claims of the International Application under PCT Article 19 (a35 u.s.c. 371(c)(3)).
 - a. ☐ are transmitted herewith (required only if not transmitted by the International Bureau).
 - b. ☐ have been transmitted by the International Bureau.
 - c. ☐ have not been made; however, the time limit for making such amendments has NOT expired.
 - d. ☒ have not been made and will not be made.
8. ☐ A translation of the amendments to the claims under PCT Article 19 (35 U.S.C. 371(c)(3)).
9. ☒ An oath or declaration of the inventor(s) (35 U.S.C. 371(c)(4)).
10. ☐ A translation of the annexes to the International Preliminary Examination Report under PCT Article 36 (35 U.S.C. 371(c)(5)).

ITEMS 11. to 16. below concern other document(s) or information included:

11. ☐ An Information Disclosure Statement under 35 CFR 1.97 and 1.98.
12. ☒ An assignment document for recording. A separate cover sheet in compliance with 37 CFR 3.28 and 3.31 is included.
13. ☒ A FIRST preliminary amendment.
☐ A SECOND or SUBSEQUENT preliminary amendment.
14. ☐ A substitute specification.
15. ☐ A change of power of attorney and/or address letter.
16. ☒ Other items or information:
 18 Sheets of Formal Drawings

U.S. APPLICATION NO. (If known, see 37 C.F.R. 1.15) 097554599		INTERNATIONAL APPLICATION NO. PCT/JP98/05311		ATTORNEY'S DOCKET NUMBER: 0819-383	
17. [X] The following fees are submitted: Basic National Fee (37 CFR 1.492(a)(1)-(5)): Search Report has been prepared by the EPO or JPO \$ 840.00 International preliminary examination fee paid to USPTO (37 CFR 1.482) \$ 670.00 No international preliminary examination fee paid to USPTO (37 CFR 1.482) but international search fee paid to USPTO (37 CFR 1.445(a)(2)) \$ 760.00 Neither international preliminary examination fee (37 CFR 1.482) nor international search fee (37 CFR 1.445(a)(2)) paid to USPTO \$ 970.00 International preliminary examination fee paid to USPTO (37 CFR 1.482) and all claims satisfied provisions of PCT Article 33 (2)-(4) \$ 96.00				CALCULATIONS IPTO USE ONLY	
ENTER APPROPRIATE BASIC FEE AMOUNT =				\$840.00	
Surcharge of \$130.00 for furnishing the oath or declaration later than [] 20 [] 30 months from the earliest claimed priority date (37 CFR 1.492(e)).				\$	
Claims	Number filed	Number Extra	Rate		
Total Claims	26 - 20 =	6	X \$18.00	\$108.00	
Independent Claims	9 - 3 =	6	X \$78.00	\$468.00	
Multiple dependent claim(s) (if applicable)			+ \$260.00	\$260.00	
TOTAL OF ABOVE CALCULATIONS =				\$1,676.00	
Reduction by 1/2 for filing by small entity, if applicable. Verified Small Entity Statement must also be filed. (NOTE 37 CFR 1.9, 1.27, 1.28).				\$	
SUBTOTAL =				\$1,676.00	
Processing fee of \$130.00 for furnishing the English translation later than [] 20 [] 30 months from the earliest claimed priority date (37 CFR 1.492(f)).				\$	
TOTAL NATIONAL FEE =				\$1,676.00	
Fee for recording the enclosed assignment (37 CFR 1.21(h)). The assignment must be accompanied by an appropriate cover sheet (37 CFR 3.28, 3.31). \$40.00 per property				+	\$40.00
TOTAL FEES ENCLOSED =				\$1,716.00	
				Amount to be refunded	\$
				charged	\$
a. [X] A check in the amount of <u>\$1,716.00</u> to cover the above fee is enclosed. b. [] Please charge my Deposit Account No. _____ in the amount of \$_____ to cover the above fees. A duplicate of this sheet is enclosed. c. [X] The Commissioner is hereby authorized to charge any additional fees which may be required, or credit any overpayment to Deposit Account No. <u>19-2380</u> . A duplicate copy of this sheet is enclosed. NOTE: Where an appropriate time limit under 37 CFR 1.494 or 1.495 has not been met, a petition to revive (37 CFR 1.137(a) or (b)) must be filed and granted to restore the application to pending status.					
SEND ALL CORRESPONDENCE TO: NIXON PEABODY LLP 8180 Greensboro Drive, Suite 800 McLean, Virginia 22102					
 SIGNATURE <u>Eric J. Robinson</u> NAME <u>38,285</u> REGISTRATION NUMBER					

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Docket: 0819-383

IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

In re New National Phase Application of)
Kazuo IMAMURA et al.)
International Application No. PCT/JP98/05311) Attn: US/DO/EO
International Filing Date: November 25, 1998)
For: FIBER GRATING AND METHOD)
AND APPARATUS FOR)
FABRICATING THE SAME) Date: May 26, 2000

PRELIMINARY AMENDMENT

Honorable Assistant Commissioner for Patents
Washington, D.C. 20231

Sir:

Please enter the following Amendment prior to calculating the filing fee
for the present application:

IN THE CLAIMS:

Please cancel claims 1-19 and add new claims 20-38 as follows:

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--20. A fiber grating comprising a core where a grating is written, a cladding for covering the core, and a coat layer for coating an outer face of the cladding,

wherein the coat layer is made from a UV transmitting resin and has a characteristic of transmitting UV at least of a specific wavelength band used for writing the grating and of curing by absorbing UV of a shorter wavelength band or a lower wavelength band than the specific wavelength band, and

the grating is written by irradiating the core with the UV of the specific wavelength band through the coat layer.

21. The fiber grating of claim 20, wherein the core is co-doped with Ge and Sn, and

a concentration of Ge is substantially the same as a concentration of Ge included in a core of another optical fiber to be connected to the fiber grating.

22. The fiber grating of claims 20 or 21, further comprising a secondary coat layer for coating an outer face of the coat layer,

wherein the secondary coat layer is made from a material having a negative coefficient of linear expansion.

23. The fiber grating of claim 20, wherein the coat layer is formed from a single coat film with a thickness of 30 μm or more.

24. The fiber grating of claim 21, wherein the core is further doped

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with A1.

25. A method of fabricating a fiber grating comprising the steps of:
fabricating a glass fiber structure including a core where a grating
is to be written and a cladding for covering the core;
forming a coat layer of a UV transmitting resin for covering an
outer face of the glass fiber structure; and
writing the grating in the core by irradiating the core with first UV
through the coat layer,
wherein the step of forming the coat layer includes a step of curing
the UV transmitting resin through irradiation with second UV having a different
wavelength from the first UV.

26. The method of fabricating a fiber grating of claim 25, wherein the
first UV has a wavelength of 250 nm through 350 nm.

27. The method of fabricating a fiber grating of claim 25 or 26, wherein
the coat layer is formed by a single coating method in a thickness of 30 μm
through 50 μm .

28. A method of fabricating a fiber grating comprising the steps of:
fabricating a glass fiber structure including a core where a grating
is to be written and a cladding for covering the core;
forming a coat layer of a UV transmitting resin for covering an
outer face of the glass fiber structure; and

writing the grating in the core by irradiating the core with first UV through the coat layer,

wherein the step of writing the grating includes steps of:

placing all the coat layer, the cladding and the core in a position between a cylindrical lens and a focal point of the cylindrical lens and within a beam pattern of the UV converged toward the focal point by the cylindrical lens; and

irradiating the core with the UV through the cylindrical lens.

29. A method of fabricating a fiber grating comprising the steps of:
fabricating a glass fiber structure including a core where a grating is to be written and a cladding for covering the core;

forming a coat layer of a UV transmitting resin for covering an outer face of the glass fiber structure; and

writing the grating in the core by irradiating the core with first UV through the coat layer,

wherein, in the step of writing the grating, an outer face of the coat layer is internally in contact with an outer edge of a beam pattern of the UV.

30. The method of fabricating a fiber grating of claim 25, wherein the core is loaded with hydrogen before irradiating with the first UV.

31. The method of fabricating a fiber grating of claim 25, wherein the core is co-doped with Ge and Sn.

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32. A method of fabricating a fiber grating comprising:

a tension application step of causing tensile strain along a fiber axial direction by previously applying a tensile force along the fiber axial direction to a grating write portion of an optical fiber to be fabricated into a fiber grating;

an irradiation step of writing the grating with a predetermined grating pitch along the fiber axial direction in a core of the optical fiber by irradiating the optical fiber with UV with keeping the tensile force applied in the tension application step; and

a tension release step of shifting the grating pitch of the grating written in the core toward a shorter wavelength by releasing the tensile force after the irradiation step.

33. A method of fabricating a fiber grating comprising:

a tension application step of causing tensile strain along a fiber axial direction by previously applying a tensile force along the fiber axial direction to a grating write portion of an optical fiber to be fabricated into a fiber grating;

an irradiation step of writing the grating with a predetermined grating pitch along the fiber axial direction in a core of the optical fiber by irradiating the optical fiber with UV with keeping the tensile force applied in the tension application step;

a tension release step of shifting the grating pitch of the grating written in the core toward a shorter wavelength by releasing application of the tensile force after the irradiation step; and

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a screening step of conducting a screening test on the grating write portion by applying a predetermined tensile force to the optical fiber after the tension release step.

34. A method of fabricating a fiber grating, by using a fiber grating fabrication apparatus including a UV irradiation system for irradiating, with UV, an optical fiber to be fabricated into a fiber grating and a tension applying mechanism for applying a tensile force in a fiber axial direction to the optical fiber, comprising:

an irradiation step of writing a grating along the fiber axial direction in a core of the optical fiber by irradiating the optical fiber with UV by using the UV irradiation system; and

a screening step of conducting a screening test on a portion where the grating has been written by applying a predetermined tensile force to the optical fiber by using the tension applying mechanism after the irradiation step.

35. A fiber grating fabrication apparatus comprising:

a UV irradiation system for writing a grating with a predetermined grating pitch along a fiber axial direction in a core of an optical fiber to be fabricated into a fiber grating by irradiating the optical fiber with UV; and

a tension applying mechanism for causing tensile strain along the fiber axial direction by temporarily applying a tensile force to a portion of the optical fiber irradiated with UV by the UV irradiation system,

wherein the tension applying mechanism is capable of applying a tensile force exceeding failure strength of the optical fiber.

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36. The fiber grating fabrication apparatus of claim 35, wherein the tension applying mechanism includes:

a pair of fixing means for respectively fixing two portions of the optical fiber away from each other along the fiber axial direction and sandwiching the portion of the optical fiber irradiated with UV by the UV irradiation system; and

moving means for forcedly moving at least one of the pair of fixing means along the fiber axial direction away from and toward the other of the pair of fixing means.

37. A fiber grating fabrication apparatus comprising:

a UV irradiation system for writing a grating with a predetermined grating pitch along a fiber axial direction in a core of an optical fiber to be fabricated into a fiber grating by irradiating the optical-fiber with UV; and

a tension applying mechanism for causing tensile strain along the fiber axial direction by temporarily applying a tensile force to a portion of the optical fiber irradiated with UV by the UV irradiation system,

wherein the tension applying mechanism includes:

a pair of fixing means for respectively fixing two portions of the optical fiber away from each other along the fiber axial direction and sandwiching the portion of the optical fiber irradiated with UV by the UV irradiation system; and

moving means for forcedly moving at least one of the pair of fixing means along the fiber axial direction away from and toward the other of the pair of fixing means,

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the pair of fixing means are winding reels each for fixing the optical fiber, with frictional resistance against the optical fiber, by winding the optical fiber around an axis thereof perpendicular to the fiber axial direction, one of the winding reels to be moved by the moving means being rotatably supported around the perpendicular axis in one position along the fiber axial direction, and

the moving means is a motor for forcedly rotating one of the winding reels to be moved by predetermined revolutions with the optical fiber wound.

38. The method of fabricating a fiber grating of any of claims 25-26 and 28-31, wherein the coat layer is formed in a large thickness for exhibiting a mechanical strength characteristic equivalent to that of a coated fiber to be connected to the fiber grating, and


the UV irradiated for writing the grating is obtained by using solid laser and irradiates the core at an irradiation energy density of 1.5 through 4.0 kJ/cm².--

REMARKS

Claims 1-19 have been canceled and new claims 20-38 have been added to conform the subject application to the Article 34 Amendment filed in the international stage.

Examination on the merits is requested.

Respectfully submitted,



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Description

FIBER GRATING AND

METHOD AND APPARATUS FOR FABRICATING THE SAME

Technical Field

The present invention relates to a fiber grating in which a diffraction grating (grating) exhibiting a periodical index difference is written in a core of an optical fiber, and a method and an apparatus for fabricating the same.

Background Art

A conventionally known fiber grating of this type includes a grating written in a core of an optical fiber by a two-beam interference method or a phase mask method (for example, as disclosed in Japanese Laid-Open Patent Publication No. 6-235808, Japanese Laid-Open Patent Publication No. 7-140311 and Japanese Patent No. 2521708). In such a fiber grating, a fused quartz (core) doped with germanium (Ge) is irradiated with a coherent UV laser beam so as to generate (write) a Bragg grating by causing photo-induced refractive index change in an irradiated portion.

The optical fiber used as the target for writing is generally obtained by coating a core and a cladding with a coat layer of a UV curable resin or the like that is cured by absorbing UV. The coat layer formed on a write target portion is generally removed in writing the grating through the UV irradiation in employing

either of the two-beam interference method and the phase mask method, and the portion from which the coat layer is removed is coated again after completing writing the grating.

When the coat layer is removed, however, the outer face of a non-coated fiber (the outer face of the cladding) is exposed to air, and there is a fear of degradation of the non-coated fiber proceeded through the exposure to air during the writing work, which can degrade the transmitting characteristic. In addition, the coat layer of the write target portion is removed not by mechanical means but by a chemical treatment for dissolving it with, for example, a chemical, so as not to damage the non-coated fiber. Therefore, the removal of the coat layer is troublesome, which is a factor in degrading efficiency in mass processing for writing the grating.

On the other hand, in order to effectively write the grating by UV irradiation through the coat layer without removing the coat layer, sensitivity of the core of the optical fiber, that is, the target for writing, to the photo-induced refractive index change (photosensitivity) may be possibly increased. As means for increasing the photosensitivity, namely, means for causing comparatively large photo-induced refractive index change, it has been proposed that the core corresponding to the target for writing is doped with Ge in a higher concentration (a concentration for attaining a relative refractive index difference between the core and the cladding of, for example, 1.5 through 2.0%) than

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written is expanded or shrunk due to an influence of temperature change or an externally applied tensile force, the reflective wavelength of the grating is shifted. Therefore, a fiber grating is required to have a mechanical strength characteristic and a stable temperature characteristic that it cannot be expanded/shrunk by temperature change.

The present invention was devised in consideration of these circumstances, and an object is providing a fiber grating in which a grating can be easily written without causing degradation of the transmitting characteristic. In addition, another object is providing a highly reliable fiber grating by stabilizing not only the transmitting characteristic but also the temperature characteristic.

Another object of the invention is providing a fiber grating and a method of fabricating the same in which the transmitting characteristic and the mechanical strength characteristic can be consistent with each other without spoiling improvement of productivity.

Disclosure of the Invention

The fiber grating of this invention includes a core where a grating is written, a cladding for covering the core, and a UV transmitting resin layer for coating the outer face of the cladding, and the grating is written in the core by irradiating the core through the resin layer with UV of a specific wavelength

band.

Since the coat layer covering the core and the cladding is made from a UV transmitting resin in this fiber grating, even when UV is irradiated through the coat layer, the UV transmits the coat layer to effectively irradiate the core, so that the grating can be written in the core. Accordingly, the grating can be written without removing the coat layer. Therefore, it is possible to avoid degradation of the transmitting characteristic accompanied by the removal of the coat layer as well as to easily fabricate the fiber grating with a process for removing the coat layer omitted.

The coat layer of the UV transmitting resin has a characteristic of transmitting at least UV of a specific wavelength band used for writing the grating. In this case, a preferred coat layer of a UV transmitting resin is concretely specified as follows: The preferred coat layer transmits UV of the specific wavelength band used for writing the grating, for example, a wavelength band of 250 nm through 270 nm. The UV transmitting resin may have a specific wavelength band (transmitting band) within a range between 250 nm and 350 nm. As a light source of the UV having such a wavelength band, one having high spatial coherency, such as solid laser, is preferably used.

The coat layer has a characteristic of curing by absorbing UV in a shorter wavelength band or a longer wavelength band than the specific wavelength band used for writing the grating.

In using the coat layer of this invention, the grating can be written by UV irradiation through the coat layer because it transmits UV in the specific wavelength band, and at the same time, the coat layer absorbs UV and cures in the formation thereof so as to work as a protecting coat of the optical fiber.

The core is preferably co-doped with at least Sn in addition to Ge in an amount equivalent to that in the core of an optical fiber to be connected. The amount of Ge to be doped is preferably that for attaining a relative refractive index difference between the cladding and the core of approximately 0.9%, while the concentration of Sn is preferably 10000 through 15000 ppm.

The co-doped Sn (tin) stationarily increases the photo-induced refractive index change of the core as compared with a core doped with Ge alone in a general concentration. As a result, the reflectance attained by irradiating with the UV can be increased as compared with that of the core doped with Ge alone in the general concentration. Specifically, a specific wavelength (Bragg wavelength) λ_B reflected by a grating is represented by the following formula (1), and the reflectance RB for reflecting light of the Bragg wavelength is represented by the following formula (2):

$$\lambda_B = 2 \cdot n \cdot P \quad \dots (1)$$

n: Effective refractive index

P: Grating pitch

$$RB = \tanh^2(\pi \cdot L \cdot \Delta n \cdot \eta / \lambda_B) \quad \dots (2)$$

L: Grating length

Δn : Refractive index modulation

η : Propagation optical energy included in a core region

5 In the case where the core co-doped with Sn is irradiated with UV, the refractive index modulation Δn is larger than in the core doped with Ge alone in the general concentration, resulting in increasing the reflectance RB. Accordingly, by forming the coat layer from the UV transmitting resin, not only the grating
10 can be effectively written without removing the coat layer but also the co-doped Sn can increase the reflectance of the written grating.

In addition, since the concentration of the doped Ge is equivalent to that in the core of an optical fiber to be connected,
15 connection loss can be prevented from increasing even when the fiber grating is connected to the optical fiber with the general specifications. Moreover, since the reflectance can be stationarily increased by co-doping Sn without conducting the high pressure hydrogen loading, the restriction in the time period
20 for forming a grating as in the case where the high pressure hydrogen loading is conducted can be avoided.

The mechanism of the photo-induced refractive index change through UV irradiation has not been made clear yet although various ideas including the following have been proposed: An idea based
25 on the Kramers-Kronig mechanism that the refractive index change

is caused due to the bond between a Ge atom and SiO₂ (quartz glass) changed through the UV irradiation; an idea based on a compression model that a glass bond cut through the UV irradiation causes collapse of the glass structure so as to increase the density, resulting in increasing the refractive index; and an idea based on a dipole model. Also, the mechanism of increase of the photo-induced refractive index change by co-doping Sn has not been made clear. The present inventors have, however, variously examined and tested materials to be doped in a core, premising that the high pressure hydrogen loading, which requires troubles and rather long time (for example, of two weeks) and is restricted in the time period for forming a grating, is not used and that the amount of Ge to be doped is set equivalently to that of the general specifications for avoiding the connection loss, resulting in finding that the reflectance can be increased by co-doping Sn as described above without causing the conventional problems.

Furthermore, the coat layer of the UV transmitting resin is preferably covered with a secondary coat layer after writing the grating. The secondary coat layer is formed from a material having a negative coefficient of linear expansion so as to cancel the expansion, caused by temperature change, of a glass part of the optical fiber having a positive coefficient of linear expansion. The secondary coat layer having a negative coefficient of linear expansion is formed from, for example, a liquid crystal polymer (LCP). In using the LCP, even when the core and the cladding show

range, it is possible to obtain a fiber grating having a transmitting characteristic with high reflectance without degrading the strength of the coat layer.

Specifically, after forming the coat layer of a UV transmitting resin in a large thickness so as to attain a mechanical strength characteristic equivalent to that of a coated fiber to be connected to the fiber grating, the UV irradiation is conducted at an irradiation energy density of at least approximately 1.5 through 4.0 kJ/cm². In this case, even when the coat layer has a large thickness for attaining the mechanical strength characteristic equivalent to that of the coated fiber to be connected, a grating having a good transmitting characteristic with high reflectance can be written in the core, that is, the target for writing, by conducting the UV irradiation at the aforementioned irradiation energy density, and degradation of the strength of the glass part and the coat layer due to the UV irradiation can be minimized so as to keep the aforementioned mechanical strength characteristic. In addition, since the thick coat layer is formed before writing the grating, the fiber grating can be mass produced without spoiling improvement of productivity. Fiber gratings are classified into a short-period fiber grating for attaining refractive index modulation of a 0.5 μm period for realizing back coupling to a core and a long-period fiber grating for attaining refractive index modulation of a 100 through 500 μm period for realizing front coupling to a cladding, to both

types of which the invention is applicable.

From the viewpoint of productivity, the coat layer is most preferably formed by single coating immediately after drawing a non-coated fiber. The "thickness" of the coat layer may be determined so as to attain, after writing the grating, substantially the same mechanical strength characteristic as that of a general communication coated fiber to be connected to the fiber grating. Specifically, the thickness is at least approximately 30 μm . In a non-coated fiber of 125 μm , the coat layer is preferably formed in a thickness of 30 through 50 μm , for example, of 37.5 μm . According to this invention, since the coat layer is not removed in writing the grating, the strength of the optical fiber is minimally reduced, and hence, sufficient mechanical strength can be attained even when the coat layer has a thickness of 50 μm or less.

Also, the "irradiation energy density" of the UV is preferably set within the range between 1.5 and 4.0 kJ/cm^2 in order to suppress increase of the Young's modulus of the coat layer within a predetermined range. The UV irradiation may be conducted by any of various methods, for example, by repeating irradiation at a predetermined pulse frequency with a short pulse width and with a constant energy of each pulse; by continuous irradiation; and by intermittent irradiation with large energy at intervals.

The UV irradiation at such an irradiation energy density may be conducted with the UV converged by a cylindrical lens,

and in this case, the entire coat layer is placed in a position within a beam pattern of the UV converged toward a focal point.

When UV is converged by the cylindrical lens, the irradiation density of the UV is highest at the focal point. However, when the UV irradiation is conducted through the coat layer of the coated fiber as the target for writing, the coat layer can be locally damaged, for example, burnt or changed in color (yellowed) by placing the coated fiber on the focal point. When the entire coat layer is placed within the beam pattern as described above, the coated fiber can be uniformly irradiated at the predetermined irradiation density without damaging the coat layer. In addition, from the viewpoint of shortening time for the irradiation process, the coated fiber as the target for writing is most preferably placed not only within the beam pattern but also in a position where the outer face of the coat layer of the coated fiber is internally in contact with the outer edge of the beam pattern. Specifically, the position for attaining the internal contact corresponds to a position closet to the focal point and a position for the entire coat layer placing within the beam pattern, and hence, the UV can be irradiated at the highest irradiation density in a range where the damage of the coat layer is avoided.

Moreover, when the core is loaded with hydrogen before the UV irradiation, the photo-induced refractive index change caused by the UV irradiation can be increased, resulting in forming a grating with further higher reflectance. Furthermore, when the

core as the target for writing is co-doped with at least Sn in addition to Ge, the photo-induced refractive index change caused by the UV irradiation can be increased even if the concentration of the doped Ge is equivalent to that in a coated fiber to be connected, resulting in forming a grating with further higher reflectance.

In conducting the UV irradiation through the coat layer, when the fiber grating is to be fabricated by irradiating with UV converged by the cylindrical lens, the optical fiber bearing the coat layer is preferably placed in a position between the cylindrical lens and a focal point of the cylindrical lens so that the entire optical fiber including the coat layer can be positioned within a beam pattern of the UV converged toward the focal point by the cylindrical lens.

Since the irradiation density of the UV is the highest at the focal point to which the UV is converged by the cylindrical lens, when the UV irradiation is conducted not through the coat layer but with the coat layer removed, the glass part from which the coat layer is removed is disposed as close as possible to the focal point. However, when the UV irradiation is conducted through the coat layer as in this invention, the coat layer is locally damaged to be burnt or changed in color (yellowed) by disposing the coated fiber on the focal point. When the coated fiber is disposed so as to place the entire coat layer within the beam pattern, however, the coated fiber can be uniformly

irradiated at the predetermined irradiation density without
damaging the coat layer.

In particular, the coated fiber is most preferably placed
not only within the beam pattern but also in a position where
the outer face of the coat layer is internally in contact with
the outer edge of the beam pattern. Specifically, the position
for attaining the internal contact corresponds to a position
closest to the focal point and a position for the entire coat
layer placing within the beam pattern. Therefore, the UV can be
irradiated at the highest irradiation density within the range
where the damage of the coat layer is avoided. In this manner,
the time required for writing the grating can be shortened,
resulting in improving the efficiency of fabrication of the fiber
grating.

The core is preferably loaded with hydrogen before the UV
irradiation, or preferably co-doped with at least Sn in addition
to Ge.

In another method of fabricating a fiber grating of this
invention, a grating is written in a state where tensile strain
is caused by applying a tensile force. Thereafter, when the
applied tensile force is released so as to elastically restore
the tensile strain, the grating pitch of the grating written in
a core is narrowed correspondingly to the elastically restored
tensile strain. Thus, the wavelength characteristic can be
shifted toward a shorter wavelength, and in addition, the shift

toward a shorter wavelength can be stably kept.

Specifically, according to the invention, a tension application step of causing tensile strain along a fiber axial direction by previously applying a tensile force along the fiber axial direction to a portion for writing a grating of an optical fiber to be fabricated into a fiber grating; an irradiation step of writing the grating with a predetermined grating pitch along the fiber axial direction in the core of the optical fiber by irradiating, with UV, the optical fiber with the tensile force applied in the tension applying step; and a tension release step of shifting the grating pitch of the grating written in the core toward a shorter wavelength by releasing the applied tensile force after the irradiation step are executed.

In this case, tensile strain (expansion strain) is caused along the fiber axial direction in the core of the optical fiber in the tension application step, so as to keep the core to be expanded along the fiber axial direction. Next, the irradiation step is conducted under this condition, so as to write the grating with the predetermined grating pitch in the expanded core. Then, the tensile force applied to the optical fiber where the grating has been written is released in the subsequent tension release step, thereby elastically restoring the expansion strain. Accordingly, the grating pitch of the written grating is shifted to be narrowed. As a result, the wavelength of light reflected by the grating is shifted toward a shorter wavelength

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correspondingly to the narrowed grating pitch. Therefore, the shift control of the wavelength characteristic toward a shorter wavelength, which cannot be realized by a conventional tension applying method for keeping an applied tensile force after writing a grating, can be realized by the present method. Also, in this case, differently from the conventional tension applying method, the grating is written under application of the tensile force and the tensile force is released thereafter. Therefore, the grating shifted toward a shorter wavelength is stably formed in the core of the optical fiber under application of no load, and hence, the wavelength characteristic shifted toward a shorter wavelength of the fiber grating can be stably obtained. Moreover, as compared with the conventional tension applying method, there is no need to keep the applied tension in an individual optical fiber, and therefore, a fiber grating easily dealt with and controlled in the wavelength by tension application can be easily mass produced.

The optical fiber used in the fabrication of the fiber grating may be a non-coated fiber formed of a core and a cladding, namely, one excluding a coat layer, which does not limit the invention, and a coated fiber obtained by coating the non-coated fiber with a coat layer can be used. In this case, in order to transmit UV for effectively causing the photo-induced refractive index change in the core through the UV irradiation, the coat layer is preferably formed from a UV transmitting resin. When the UV irradiation is

system for fiber gratings.

The screening step may be conducted subsequently to a general fiber grating fabrication method in which the irradiation step alone is conducted for writing a grating without conducting the tension application step and the tension release step. Thus, in the fabrication of a fiber grating, writing of the grating and the screening test for the fiber grating where the grating has been written can be carried out in continuous procedures, and this is also suitable for the mass production system for fiber gratings.

The fiber grating fabrication apparatus of this invention includes a UV irradiation system for irradiating an optical fiber with UV so as to write a grating with a predetermined grating pitch along a fiber axial direction in a core of the optical fiber; and a tension applying mechanism for causing, by temporarily applying a tensile force, tensile strain along the fiber axial direction in a portion of the optical fiber irradiated with the UV by the UV irradiation system.

The "UV irradiation system" includes any apparatus and mechanism for writing a grating by irradiating, with UV and preferably a UV laser beam, the optical fiber over a range in the axial direction for writing the grating, and includes, for example, a laser source, a phase mask, a mechanism for changing a position irradiated with the laser beam and the like. Also, the "tension applying mechanism" may be realized by a structure

for fixing the positions of two portions of the optical fiber sandwiching the portion irradiated with UV by using adhering or frictional means and for applying a tensile force to the portion irradiated with UV by moving one or both of the fixed portions along the axial direction.

The tension application step is conducted by the tension applying mechanism for applying and keeping the tensile force along the fiber axial direction to the portion irradiated with UV, and the irradiation step is conducted by the UV irradiation system for irradiating with UV with the tensile force applied. Thus, the grating can be written through the UV irradiation in the core where tensile strain along the fiber axial direction is caused by the tension application. Then, the tension release step is carried out by releasing the applied tensile force by the tension applying mechanism after writing the grating. In this manner, the core shrinks along the fiber axial direction to restore, and the written grating shrinks in the fiber axial direction in accordance with the shrinkage of the core, resulting in narrowing the grating pitch as compared with that initially written. As a result, the wavelength of light reflected by the grating can be shifted toward a shorter wavelength than that reflected by the initially written grating.

The "tension applying mechanism" may be specifically constructed from a pair of fixing means for fixing two portions of the optical fiber away from each other in the fiber axial

whose revolutions can be determined in proportion to the number of input pulses.

Moreover, in using the fiber grating fabrication apparatus, when the irradiation step and the screening step alone are to be conducted, the writing of the grating and the screening test of the fiber grating where the grating has been written can be both carried out in the same fabrication apparatus. Specifically, after writing the grating, through the UV irradiation by the UV irradiation system, in the optical fiber under application of no load, a tensile force for causing predetermined expansion strain along the fiber axial direction for the screening test is applied by the tension applying mechanism.

Brief Description of Drawings

Figure 1 is a schematic diagram for showing a method of writing a grating according to an embodiment of the invention.

Figure 2 is a horizontal sectional view of a coated fiber obtained by further coating a coated fiber of Figure 1 with a secondary coat layer.

Figure 3 is a diagram for showing a necessary coefficient of linear expansion of the secondary coat layer as the relationship between a cross-sectional area and a Young's modulus.

Figure 4 is a schematic diagram of a use for a fiber grating of the embodiment.

Figure 5 is a schematic diagram of another use different

from that of Figure 4.

Figure 6 is a schematic diagram of still another used different from those of Figures 4 and 5.

Figure 7 is a diagram for showing the characteristics of strain change and phase change against temperature change.

Figure 8 is a diagram for showing the characteristic of absorption against a wavelength.

Figure 9 is a diagram for showing the reflectance characteristics of various fiber gratings against UV irradiation time.

Figure 10 is a schematic diagram of a fabrication apparatus.

Figure 11 is a diagram for showing the positional relationship between a coated fiber and a cylindrical lens system.

Figure 12 is an enlarged horizontal sectional view of the coated fiber.

Figure 13 is a diagram for showing the dependence of UV absorbance on an irradiation energy density.

Figure 14 is a diagram of a reflection spectrum of the fiber grating.

Figure 15 is a diagram of a Weibull distribution of failure strength of the fiber grating.

Figure 16 is a diagram for showing the temperature characteristic of a center wavelength of the fiber grating.

Figure 17 is a diagram for showing the tension application characteristic of the center wavelength of the fiber grating.

Figure 18 is a schematic diagram for showing a fiber grating fabrication apparatus according to an embodiment of the invention.

Figure 19 is an enlarged explanatory diagram of a tension applying mechanism of Figure 18.

Figure 20 is an enlarged sectional view taken on line A-A of Figure 19.

Best Mode for Carrying Out the Invention

[EMBODIMENT 1]

An embodiment of a fiber grating according to the invention will now be described with reference to the accompanying drawings.

Figure 1 shows the principle of a method of fabricating a fiber grating of this embodiment. In Figure 1, a coated fiber 1 in a given length serving as a target for writing a grating is shown. The coated fiber 1 includes a core 2 in which a Bragg grating 21 is to be written, a cladding 3 formed around the core 2, and a coat layer 4 for coating the outer face of the cladding 3.

The core 2 is doped with Ge in a concentration equivalent to that of Ge included in the core of an optical fiber with the general specifications. In order to stationarily increase photo-induced refractive index change, the core 2 is preferably doped not only with Ge but also with another dopant of Sn, Sn and Al, or Sn, Al and B. Herein, an optical fiber with the general specifications means a coated fiber to be connected to the coated

fiber 1. The core of the coated fiber with the general specifications is generally doped with Ge in a concentration for attaining a relative refractive index difference of approximately 0.9%.

5 The core 2 of the coated fiber 1 is doped not only with Ge in a concentration equivalent to that in the core of the optical fiber with the general specifications (a concentration for attaining a relative refractive index difference of approximately 0.9%) but also with Sn in a concentration of 10000 ppm or more, 10 and preferably 10000 through 15000 ppm. In addition to Sn in such a concentration, Al or the like in a concentration of 1000 ppm or less can be co-doped.

15 The addition of the dopant can be carried out by any of various known methods. For example, when the addition is carried out by immersion, a compound of Ge or Sn (with respect to Sn, for example, $\text{SnCl}_2 \cdot 2\text{H}_2\text{O}$) is mixed with methyl alcohol, and the core is immersed in the resultant solution.

20 The primary coat layer 4 is made from a UV transmitting resin having a characteristic of transmitting UV. The primary coat layer 4 may be made from any resin that can transmit at least a specific wavelength band (for example, a wavelength band of 250 nm through 270 nm) of UV irradiated for writing the grating 21. Preferably, it is made from a resin that scarcely absorbs but transmits UV in the specific wavelength band but cures by 25 absorbing UV of a wavelength shorter than or longer than the specific

4 constituting the outer face layer of the coated fiber 1 is made from the UV transmitting resin, it can transmit the UV laser beam so that the core 2, that is, the target for writing, can be effectively irradiated. As a result, the grating 21 can be easily written in the core 2. Accordingly, the grating 21 can be easily written without removing the primary coat layer, and hence, the conventional troublesome process for removing the coat layer can be omitted. Thus, mass production of the fiber grating can be easily and efficiently carried out.

Since the core 2 corresponding to the target for writing is co-doped with Sn or Sn and Al in addition to Ge, the irradiation with the UV laser beam can cause comparatively large photo-induced refractive index change (namely, the photosensitivity can be improved), so as to form the grating 21 with high reflectance.

Moreover, since the high reflectance of the grating 21 can be thus attained by doping the core with Ge in the same amount as that in the optical fiber with the general specifications, there is no fear of occurrence of connection loss derived from mismatching in the amount of doped Ge even when the both ends of the coated fiber 1 constituting the fiber grating are connected to coated fibers with the general specifications. In addition, since the increase of the photo-induced refractive index change is stationary, it is possible to avoid the restriction in the period for forming the grating as in the case where the high reflectance is attained by conducting the high pressure hydrogen loading.

area in addition to the negative coefficient of linear expansion of the secondary coat layer 7, namely, the positive and negative temperature characteristics can be balanced.

An example of the concrete specifications of the secondary coat layer 7 determined in accordance with this course will now be described with reference to Figure 3. In the case where the positive coefficient of linear expansion of the glass part F is 0.6 ppm/°C, the Young's modulus is 73 GPa, the cross-sectional area is 0.0123 mm² (with an outer diameter of 0.125 mm) and the outer diameter of the primary coat layer 4 is 0.25 mm, the concrete specifications of the secondary coat layer 7 are shown in Figure 3 with the cross-sectional area, the coefficient of linear expansion and the Young's modulus of the secondary coat layer 7 used as parameters. Specifically, in the case where the Young's modulus of the secondary coat layer 7 is set to 10 GPa, 30 GPa or 50 GPa and the cross-sectional area is changed by variously changing its outer diameter, the negative coefficient of linear expansion of the secondary coat layer 7 required to be balanced with the positive temperature characteristic of the glass part F can be obtained from Figure 3. According to Figure 3, the secondary coat layer 7 should have a coefficient of linear expansion of -5 ppm/°C through -10 ppm/°C regardless of the cross-sectional area excluding a region where the cross-sectional area is as small as 0.1 mm² or less. In addition, as the value of the Young's modulus is larger (harder), the absolute value of the negative coefficient

positive coefficient of linear expansion in accordance with increase of the atmosphere temperature, the secondary coat layer 7 is to shrink due to its negative coefficient of linear expansion in accordance with the temperature increase. Accordingly, the expanding force of the glass part F and the shrinking force of the secondary coat layer 7 are mutually interfered through the primary coat layer 4 to be balanced, resulting in suppressing and preventing the expansion of the glass part F and keeping it in the same state as that attained prior to the temperature increase.

In addition, the secondary coat layer 7 is formed not locally in the portion for writing the grating 21 but continuously along the entire length of the coated fiber 1' constituting the fiber grating. Therefore, the balance between the expanding force of the glass part F and the shrinking force of the secondary coat layer 7 can be attained along the entire length of the coated fiber 1', resulting in stabilizing the mechanical strength characteristic of the entire fiber grating.

Examples of the use of the fiber grating in which the grating 21 is written are as follows: For example, when it is used as an optical demultiplexer or an optical multiplexer, in transmitting light of a wavelength band with a comparatively small width including a large number of different wavelengths λ_1 through λ_n as is shown in Figure 4, light of a specific wavelength λ_i alone can be reflected so as to isolate the light of the specific wavelength λ_i through a circulator 8. This structure can be used,

for example, in the field of Add-Drop type wavelength division multiplex communications.

Alternatively, it can be formed as a chirped fiber grating 21' as is shown in Figure 5 so as to be used as a substitute for a multi-layered film filter. Specifically, light of a specific wavelength band (a center wavelength λ_i) among plural wavelength bands (λ_1 through λ_n) can be reflected so as to cut the light of the specific wavelength band and transmit light of the wavelength bands other than specific wavelength band. As an example of the application of the chirped fiber grating 21', by utilizing the delay characteristic that light of a longer wavelength in the specific wavelength band is reflected at the earlier stage and light of a shorter wavelength is reflected later, it can be used as a dispersion compensator for taking out the reflected wave by using a circulator and transmitting it in a dispersed state.

Furthermore, when the grating 21 is formed on both sides of an amplifier medium 9 as shown in Figure 6, a resonator in which each grating 21 works as a laser mirror can be obtained. Specifically, light of a specific wavelength is reflected between the gratings 21 on both sides of the amplifier medium 9.

According to this embodiment, since the grating 21 or 21' used in each of the aforementioned uses can be improved in the reflectance, the light of a specific wavelength or a specific wavelength band can be substantially completely reflected, so as to take out or cut the substantially entire light of the specific

wavelength or the specific wavelength band.

The invention is not limited to the aforementioned embodiment but can be practiced in various other embodiments. Specifically, the metal elements to be co-doped in addition to Ge are Sn or Sn and Al in the aforementioned embodiment, but the metal elements are not limited to them, and for example, one of or two or more of metal elements such as cesium (Ce), praseodymium (Pr), terbium (Tb) and boron (B) can be co-doped in addition to Ge. Moreover, a combination of Sn and any of these metal elements can be co-doped in addition to Ge.

<Example 1>

It was examined whether or not a grating could be effectively written by UV irradiation through the primary coat layer 4 of a UV transmitting resin.

Specifically, a non-coated fiber including a core 2 co-doped with Ge, Sn and Al was used to fabricate the following three samples: Sample 1 was fabricated by coating the non-coated fiber with the primary coat layer 4 of a UV transmitting resin to obtain the coated fiber 1 and writing a grating in the coated fiber 1 through UV irradiation through the primary coat layer 4; Sample 2 was fabricated by loading hydrogen at a high pressure in the core 2 of the non-coated fiber, coating the non-coated fiber with the primary coat layer 4 of a UV transmitting resin the same as that used in the first example to obtain the coated fiber 1, and writing a grating in the coated fiber 1 through UV irradiation through

the primary coat layer 4; and Sample 3 was fabricated by loading hydrogen at a high pressure (hydrogen treatment) in the core 2 of the non-coated fiber in the same manner as in the second example, and writing a grating through UV irradiation without coating the non-coated fiber with the primary coat layer 4. Each of these samples was examined for the reflectance of the grating, and the center wavelength and the wavelength width of the maximum reflective wavelength band in a reflection spectrum represented by the relationship between the wavelength and the reflectance.

Each of Samples 1, 2 and 3 will be specifically described. The non-coated fiber had a diameter of 125 μm , a mode field diameter of 6.2 μm and a cut-off wavelength of 1.28 μm , and the core of the non-coated fiber was co-doped with Ge in a concentration for attaining a relative refractive index difference Δ of approximately 0.9%, Sn in 15000 ppm and Al in 1000 ppm. In Sample 1, the non-coated fiber was coated with the primary coat layer 4 of a UV transmitting resin adjusted to have a transmission characteristic, in the vicinity of 250 nm, approximately 10 times or more as high as the transmittance of a general UV curable resin.

Also, in Sample 2, the core of the non-coated fiber was loaded with hydrogen at a high pressure, and the resultant non-coated fiber was coated with the primary coat layer 4 of the same UV transmitting resin as that used in Sample 1. Furthermore, in Sample 3, the core was loaded with hydrogen at a high pressure in the same manner as in Sample 2, and the non-coated fiber was

directly used without forming the primary coat layer 4. The high pressure hydrogen loading was conducted by sealing the core within a sealed vessel loaded with hydrogen at a high pressure of approximately 200 MPa for a predetermined period of time ranging between 1 week and 2 weeks.

Furthermore, the Bragg grating was written in each of Samples 1, 2 and 3 by using a UV laser source operated at 266 nm, that is, a frequency-quadrupled wavelength of YAG laser, with a pulse width of 50 ns and a repeating frequency of 10 Hz by the phase mask method using the phase mask 5 and the lens system 6 having a laser emission power of 10 mW for converging the UV (as shown in Figure 1). Each grating 21 formed through the UV irradiation had a grating length of 10 mm.

As a result of writing the Bragg grating, the grating having a center wavelength in the vicinity of 1549 nm was formed in each of Samples 1, 2 and 3, and these gratings had reflectance and wavelength widths as listed in Table 1:

Table 1:

Sample	Primary coat layer	Hydrogen treatment	Grating length	Reflectance	Wavelength width
1	formed	not conducted	10 mm	8%	0.10 nm
2	formed	conducted	10 mm	80%	0.12 nm
3	not formed	conducted	10 mm	99%	0.15 nm

As shown in Table 1, in Samples 1 and 2, which are examples of the invention where the UV laser beam is irradiated through

end. The strain was obtained based on the phase difference between the input light and the output light.

As a result, as is shown in Figure 7, even when the temperature was changed in the range between -20°C and $+100^{\circ}\text{C}$, the coefficient of linear expansion was changed merely by 1 ppm/ $^{\circ}\text{C}$, and the shift of the center wavelength in accordance with the temperature change could be suppressed to be very small.

The transmission characteristic measured in the UV transmitting resin used for forming the primary coat layer 7 of Samples 1 and 2 is shown in Figure 8. This is absorption of the UV transmitting resin in a thickness of 20 μm against light of respective wavelengths. As is shown with a solid line in Figure 8, the absorption is very small in the wavelength band of 240 nm through 270 nm, which is used in writing the grating, while UV of the wavelength band shorter than 240 nm is sufficiently absorbed so as to accelerate the curing reaction.

<Test Example>

It was confirmed that the reflectance is increased by co-doping Sn or the like in addition to Ge in a general concentration.

Specifically, the following samples were fabricated so as to compare their performance in the reflectance: In Sample 4, that is, an example of the invention, the grating was written in a core co-doped with Ge in a concentration of the general specifications and Sn; in Sample 5, the grating was written in

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a core doped with Ge alone in a concentration of the general specifications; and in Sample 6, the grating was written in a core doped with Ge alone in a higher concentration than in the general specifications.

5 Now, Samples 4, 5 and 6 will be specifically described. In each sample, the non-coated fiber had an outer diameter of 125 μm , a mode field diameter of 6 μm and a cut-off wavelength of approximately 1.3 μm . In Sample 4, the core was co-doped with Ge in a concentration for attaining the relative refractive index difference Δ of 0.9% and Sn in a concentration of 10000 ppm, so as to attain the relative refractive index difference Δ of 1.0%. In Sample 5, the core was doped with Ge alone in a concentration for attaining a relative refractive index difference Δ of approximately 0.9%, and in Sample 6, the core was doped with Ge alone in a concentration for attaining a relative refractive index difference Δ of approximately 2.0%.

Furthermore, with respect to each type of cores of the samples, two kinds were prepared, one of which was loaded with hydrogen at a high pressure and the other was not loaded with hydrogen (without the hydrogen treatment), so as to compare the core obtained without the hydrogen treatment and the core loaded with hydrogen. Accordingly, Samples 4, 5 and 6 without the hydrogen treatment are respectively designated as E-1, N-1 and H-1, and Samples 4, 5 and 6 loaded with hydrogen at a high pressure are respectively designated as E-2, N-2 and H-2. The high pressure

hydrogen loading was conducted by sealing the core in a sealed vessel loaded with hydrogen at a high pressure of approximately 200 MPa for a predetermined period of time in a range between 1 week and 2 weeks.

The grating was written in the non-coated fiber of each of Samples E-1,2 , N-1,2 and H-1,2, similarly to the first test example, by using a UV laser source operated at 266 nm, that is, a frequency-quadrupled wavelength of the YAG laser, with a pulse width of 50 ns and a repeating frequency of 10 Hz, by the phase mask method using the phase mask 5 and the lens system 6 having the laser emission power of 10 mW for converging the UV, with variously changing the irradiation time (as shown in Figure 1). At this point, a grating with a grating length of 0.3 mm was formed in each of Samples E-1, N-1 and H-1, and a grating with a grating length of 2.0 mm was formed in each of Samples E-2, N-2 and H-2.

The reflectance characteristics against the UV irradiation time of the six kinds of Samples E-1, N-1, H-1, E-2, N-2 and H-2, which are different from one another in the three kinds of dopes and in the high pressure hydrogen loading are shown in Figure

9.

On the basis of Figure 9, the samples obtained without the hydrogen treatment are compared as follows: In Sample E-1 that was co-doped with Sn in addition to Ge, the reflectance increased as the irradiation time increased, and reflectance of approximately 70% was attained when the irradiation time was 40

through 50 minutes. In Sample N-1 that was doped with Ge alone in the general concentration, although the reflectance increased as the irradiation time increased, reflectance of merely approximately 30% was attained when the irradiation time was 40 through 50 minutes. In Sample H-1 that was doped with Ge alone in a high concentration, the reflectance increased as the irradiation time increased, and reflectance of approximately 75% was attained when the irradiation time was 40 through 50 minutes.

Accordingly, in Sample E-1, the reflectance can be increased without the high pressure hydrogen loading by co-doping Sn in addition to Ge in the general concentration as compared with Sample N-1 doped with Ge alone in the general concentration, and in addition, Sample E-1 attains high reflectance substantially equivalent to that of Sample H-1 doped with Ge in a high concentration for attaining the relative refractive index difference of 2.0%.

Furthermore, the samples obtained by conducting the high pressure hydrogen loading are compared as follows: In Sample E-2, the reflectance rapidly increased, immediately after the start of the irradiation, to 95% or more in the irradiation time of several minutes. In contrast, in Sample N-2 that was doped with Ge alone in the general concentration, although the reflectance increased as the irradiation time increased, the reflectance of approximately 95% could not be attained until the irradiation time of 30 minutes or more elapsed, and in Sample H-2 that was doped with Ge alone in a high concentration, the reflectance

increased substantially similarly to that of Sample E-2 although it was slightly lower than that of Sample E-2.

Accordingly, also when the high pressure hydrogen loading is conducted, in Sample E-2, high reflectance substantially equivalent to that of Sample H-2 doped with Ge in a high concentration can be attained by co-doping Sn in addition to Ge in the general concentration, and in addition, high reflectance of 95% or more can be attained through UV irradiation for a very short period of time as compared with in Sample N-2 doped with Ge alone in the general concentration.

Also when the concentration of Sn to be co-doped in each of Samples E-1 and E-2 was increased from 10000 ppm to 15000 ppm, the effect of attaining high reflectance was substantially similarly exhibited.

As described above, according to the fiber grating of this invention, since the coat layer covering the core and the cladding is formed from a UV transmitting resin, a grating can be effectively written in the core by UV irradiation through the coat layer because the UV transmits the coat layer so as to effectively irradiate the core. Accordingly, the grating can be written without removing the coat layer, and hence, degradation of the transmitting characteristic accompanied by the removal of the coat layer can be avoided, and in addition, the process for removing the coat layer can be omitted, so as to ease the fabrication of the fiber grating.

When the photo-induced refractive index change of the core is stationarily increased by co-doping Sn as compared with a core doped with Ge alone in the general concentration, the formed grating can attain higher reflectance than that attained by using the core doped with Ge alone in the general concentration. Moreover, when the concentration of the doped Ge is set to the same concentration as in the core of an optical fiber to be connected, the connection loss can be prevented from increasing even when the fiber grating is connected to the optical fiber with the general specifications.

Furthermore, without conducting the high pressure hydrogen loading, the reflectance can be stationarily increased by co-doping the core with Ge and Sn, and hence, the time restriction as in forming a grating required when the high pressure hydrogen loading is employed can be avoided.

When the secondary coat layer is formed, the stability against the temperature change can be improved, which leads to stability in the mechanical strength characteristic. As a result, the shift of the reflective wavelength derived from expansion/shrinkage of the fiber can be prevented and suppressed, and the same reflecting function can be definitely retained, resulting in improving the reliability.

[EMBODIMENT 2]

A fiber grating of this embodiment basically has the same structure as that shown in Figure 1. A coat layer 4 of this

embodiment, however, is characterized by being formed in a thickness of at least approximately 30 μm by single coating subsequently to a process for drawing a non-coated fiber 1'. As the material for the coat layer 4, a UV transmitting resin having the characteristic of transmitting UV as described above is used.

Also in this embodiment, a grating 21 is written in a core 2 through UV irradiation from the outside of a coated fiber 1, namely, through the coat layer 4. The grating 21 may be written by any of various known methods. When the grating 21 is written by the phase mask method, a phase mask 5 in the shape of a grating is disposed on the immediate side of the coated fiber 1 as shown in an exemplified fabrication apparatus of Figure 10. Then, the phase mask 5 is irradiated by using a Nd-YAG laser source 6, that is, solid laser, with a coherent UV laser beam having a frequency-quadrupled wavelength (4ω), i.e., 266 nm, converged by a cylindrical lens system 7. Thus, the UV laser beam transmits the phase mask 5 and the coat layer 4, so as to write the grating 21 in the core 2 by increasing the refractive index of a portion of its grating pitch corresponding to the grating pitch of the phase mask 5. In using the solid laser, a laser beam with higher spatially coherency can be obtained than in using gas laser. When the spatially coherency is higher, a pattern can be accurately transferred even when a distance between the phase mask 5 and the core 2 is large. In the case where the core 2 covered with the coat layer 4 is irradiated with laser as in this invention,

the distance between the core 2 and the phase mask 5 is increased by the thickness of the coat layer 4, and hence, the use of the solid laser leads to a very preferable effect. Since the solid laser has smaller output light intensity than gas laser such as KrF, the laser beam is preferably converged by using a lens system such as the cylindrical lens system 7 described above.

In Figure 10, a reference numeral "8" denotes a beam expander for expanding the UV laser beam into a parallel beam, and a reference numeral "9" denotes a slit with a small width for taking out a portion with uniform power of the UV laser beam having been changed into the parallel beam. A reference numeral "10" denotes a movable reflective mirror movable along the lengthwise direction (shown with a dashed line) of the coated fiber 1, a reference numeral "11" denotes an optical spectrum analyzer, a reference numeral "12" denotes an optical isolator and a reference numeral "13" denotes an optical coupler.

Now, a method of writing a grating according to this embodiment will be described in detail.

In this embodiment, the UV laser beam irradiation is conducted at an irradiation energy density of approximately 1.5 through 4.0 kJ/cm². Thus, in conducting the UV laser beam irradiation through the coat layer 4, even when the coat layer 4 has a thickness of approximately 30 μ m or more, large refractive index modulation can be caused in the core 2 through the coat layer 4, so as to write the grating 21 having high reflectance.

where the strength degradation can be avoided, resulting in shortening the time required for writing the grating.

<Example 2>

A fiber grating fabricated by the method of the above-described embodiment was examined for the transmitting characteristic and the mechanical strength characteristic. With respect to the transmitting characteristic, the reflectance against light of a specific wavelength, the full width half maximum and the side lobe, and with respect to the mechanical strength characteristic, the stress corrosion susceptibility parameter and the failure strength of the fiber grating and change of the Young's modulus of the coat layer 4 were measured and tested.

- Specimen -

(Specifications of specimen)

The specifications of a coated fiber 1 used in the test are listed in Table 2.

Table 2:

Relative refractive index difference $\Delta(\%)$	0.97
Sn concentration (ppm)	15000
Al concentration (ppm)	900
Mode field diameter (μm)	5.55
Cut-off wavelength (nm)	1270
Diameter of cladding (μm)	125
Outer diameter of coat layer (μm)	200

A core glass co-doped with Ge in the general concentration, Sn in a concentration of 15000 ppm and Al in a concentration of 900 ppm was prepared by using both VAD and solution-doping technique, and a fiber base material obtained by collapsing a cladding glass

was drawn around the core glass, so as to obtain a non-coated fiber 1' (see Figure 12). Subsequently, the non-coated fiber 1' was covered by single coating with a coat layer 4 with a thickness of 37.5 μm of a UV transmitting type UV curable resin, thereby obtaining a coated fiber 1. The coated fiber 1 has a relative refractive index difference Δ of 0.97%, a mode field diameter of 5.55 μm , a cut-off wavelength of 1270 nm, a diameter of the cladding (the outer diameter of the non-coated fiber 1') of 125 μm , and an outer diameter of the coat layer (the outer diameter of the coated fiber 1) of 200 μm . The coated fiber 1 was sealed within a sealed vessel loaded with hydrogen at a high pressure of 20 MPa for approximately 2 weeks for conducting the high pressure hydrogen loading in the coated fiber 1.

(Test for reflection characteristic attained by co-doping Sn)

It was confirmed through increase of the reflectance of a written grating that the photo-induced refractive index change is increased by co-doping the core 2 with Sn in addition to Ge in the general concentration. Also, difference in the reflectance caused by the high pressure hydrogen loading conducted in the core 2 was also confirmed. In this test, the grating was written through UV laser beam irradiation with the coat layer 4 removed.

The following samples were fabricated so as to compare the reflection performance thereof: Sample E-1 was obtained by co-doping the core 2 with Ge in the general concentration (for attaining a relative refractive index difference Δ of the

non-coated fiber of approximately 0.9%) and Sn in 10000 ppm; Sample E-2 was obtained by conducting the high pressure hydrogen loading in the core the same as that used in Sample E-1; Sample N-1 was obtained by doping the core 2 with Ge alone in the general concentration; Sample N-2 was obtained by conducting the high pressure hydrogen loading in the core the same as that used in Sample N-1; Sample H-1 was obtained by doping the core 2 with Ge in a higher concentration than in the general specifications (for attaining a relative refractive index difference Δ of approximately 2.0%); and Sample H-2 was obtained by conducting the high pressure hydrogen loading in the core the same as that used in Sample H-1.

The reflection characteristics of six Samples E-1, N-1, H-1, E-2, N-2 and H-2 against the UV irradiation time are shown in Figure 9.

(Test for light absorbance characteristic of coat layer material)

The change of light absorbance of the resin used for forming the coat layer 4 against the UV irradiation energy density was confirmed. A sheet with a thickness of 60 μm was formed from the same material as the aforementioned resin, and the sheet was irradiated with UV under the same irradiation conditions with merely the irradiation energy density (unit: kJ/cm^2) changed between "0", "1.5" and "9.0", so as to measure the change of the light absorbance against the wavelength. The results are shown in Figure 13.

As shown in Figure 15, the maximum value of the failure strength is 5.42 GPa, the minimum value is 4.40 GPa, and the average value is 4.90 GPa, which are substantially equivalent to the failure strength of a general communication coated fiber to be connected to the fiber grating.

(Stress corrosion susceptibility parameter)

With respect to specimens obtained before and after forming the grating 21, namely, before and after the UV laser beam irradiation, a stress corrosion susceptibility parameter (n value) was obtained through evaluation of the dynamic fatigue characteristic by changing the tension rate in measurement of the failure strength between three levels.

As a result, the stress corrosion susceptibility parameter before forming the grating was found to be 23 and that after forming the grating was found to be 20 as shown in Table 3.

Table 3:

	Stress corrosion susceptibility parameter
Before forming grating	23
After forming grating	20

Although the formation of the grating slightly degrades the stress corrosion susceptibility parameter from 23 to 20 and slightly shortens the time period before braking, the stress corrosion susceptibility parameter after forming the grating is still sufficient for practical use. The stress corrosion susceptibility parameter of a general communication coated fiber to be connected to the fiber grating is approximately 23 through

24.

(Change of Young's modulus of coat layer 4)

Change of the Young's modulus of the coat layer 4 was measured against the irradiation energy density (unit: kJ/cm^2) changed between "0", "3.0" and "7.5" by respectively setting the irradiation time to 0 minute, 20 minutes and 50 minutes. Specifically, in a specimen obtained by fabricating the fiber grating under each condition, the coat layer 4 in the portion irradiated with the UV laser beam was cut along the fiber axial direction into two, namely, a front side piece facing the irradiation and a back side piece. Thus, an irradiation front coat piece 4a (see Figure 12) and an irradiation back coat piece 4b each in a semi-cylindrical shape were obtained as samples. Each of these coat pieces 4a and 4b was pulled along the fiber axial direction with a gauge length of 15 mm at a tension rate of 1 mm/min., so as to obtain the Young's modulus based on the tensile force applied for attaining expansion of 2.5%. The results are shown in Table 4.

Table 4:

Irradiation time (min)		0	20	50
Irradiation energy density (kJ/cm^2)		0	3.0	7.5
Young's modulus (MPa)	Front side	459	540	601
	Back side	459	533	540

As shown in Table 4, the Young's modulus of the irradiation front coat piece 4a, which was 459 MPa before the UV laser beam irradiation, increased to 540 MPa through the irradiation at an irradiation energy density of $3.0 \text{ kJ}/\text{cm}^2$ and to 601 MPa through

the irradiation at an irradiation energy density of 7.5 kJ/cm^2 , and thus, it increased by 17.7% and 30.9%, respectively. On the other hand, the Young's modulus of the irradiation back coat piece 4b, which was 459 MPa before the UV laser beam irradiation, increased to 533 MPa through the irradiation at an irradiation energy density of 3.0 kJ/cm^2 and to 540 MPa through the irradiation at an irradiation energy density of 7.5 kJ/cm^2 , and thus, it increased merely by 16.1% and 17.7%, respectively. Accordingly, the degree of increase of the Young's modulus of the coat layer 4 depends upon the irradiation energy density, and as the irradiation energy density increases with time of irradiation, the Young's modulus increases. In addition, the Young's modulus more largely increases in the front portion of the coat layer 4 where the irradiation energy density is higher.

At this point, when the Young's modulus of the coat layer 4 excessively increases, it becomes so hard that the flexibility of the coated fiber 1 is spoiled. As the coat layer 4 becomes harder, the coat layer 4 becomes more fragile and the strength characteristic becomes poorer. It is considered in general that the increase of the Young's modulus of the coat layer 4 within a range of 20% will not cause any problem in practical use as a coated fiber on the safest assumption. Therefore, when the irradiation energy density of the above-described example is approximately 1.5 kJ/cm^2 , the increase of the Young's modulus of the coat layer 4 causes no problem for sufficiently keeping the

flexibility and exhibiting a good strength characteristic. Moreover, even when the irradiation energy density is 3.0 kJ/cm^2 , the increase of the Young's modulus is 17.7% in the front portion, where the largest change occurs, and sufficient flexibility and strength characteristic can be still attained. In particular, as the irradiation energy density is higher, higher refractive index modulation can be caused, resulting in forming a grating with higher reflectance. Therefore, even when the thickness of the coat layer 4 is thicker than that of the example, i.e., $37.5 \mu\text{m}$, a fiber grating having both a good transmitting characteristic and a higher mechanical strength characteristic can be fabricated. With respect to the irradiation front coat piece 4a, the irradiation energy density corresponding to the increase of the Young's modulus of 20%, that is, the safest standard, obtained based on Table 3 by proportional distribution is 3.8 kJ/cm^2 . Accordingly, from the viewpoint of the flexibility of the coat layer 4, it seems that the irradiation can be conducted at an irradiation energy density up to approximately 4.0 kJ/cm^2 .

(Surface property of coat layer 4)

The coated fiber 1 was positioned as shown in Figure 11 and irradiated with the UV laser beam at an irradiation energy density of 1.5 kJ/cm^2 , so as to visually observe the surface property of the coat layer 4. As a result, the surface was found to be in a good condition having neither yellowing nor damage.

- Temperature characteristic and tension characteristic of fiber

grating -

(Temperature characteristic)

The temperature dependence and the tension dependence of the center wavelength were obtained in a fabricated fiber grating, and the results are shown in Figures 16 and 17.

It was found through the measurement that the center wavelength linearly shifts (changes) in accordance with temperature change or tension change, and Figure 16 shows that the temperature dependence is 0.011 nm/°C and Figure 17 shows that the tension dependence is 1.3 nm/N. Moreover, with respect to the tension dependence, the shift of the center wavelength was well reproduced even when a tensile force up to 40 N was repeatedly applied. Accordingly, the fiber grating is suitable for use as a temperature sensor or a tension sensor.

As described above, Embodiment 2 of the invention provides a fiber grating having a good transmitting characteristic with high reflectance as well as a mechanical strength characteristic equivalent to that of a coated fiber to be connected, attained by a coat layer with a large thickness. In addition, the strength degradation of a glass part and a coat layer accompanied by the UV irradiation can be minimized, so as to keep the mechanical strength characteristic. Accordingly, the transmitting characteristic and the mechanical strength characteristic can be consistent with each other without conducting any supplementary treatment after the UV irradiation, resulting in improving the

productivity.

Furthermore, the irradiation can be uniformly conducted at a predetermined irradiation density without damaging the coat layer. Additionally, by placing a coated fiber, that is, the target for writing, in such a position that the outer face of the coat layer is internally in contact with the outer edge of the beam pattern, the UV can be irradiated at the highest irradiation density within the range for avoiding the damage of the coat layer.

As a result, the process for writing a grating can be completed in a short period of time and the fiber grating can be efficiently fabricated.

[EMBODIMENT 3]

In the phase mask method, a phase mask corresponding to a required frequency characteristic is prepared and an optical fiber is irradiated with UV through the phase mask, so as to control the frequency characteristic of the resultant fiber grating as desired. Also, a method of shifting a written grating pitch toward a longer wavelength is known, in which after writing the grating through the UV irradiation, a tensile force is applied to the fiber grating in which the grating has been written in the fiber axial direction so that the tensile strain can remain in the fiber grating (Hiroyuki Uno, et al., "Bragg Wavelength Tuning of Fiber Grating with Tensile Strain", The Institute of Electronics, Information and Communication Engineers, National Conference 1998, C-3-123, p. 289, March 1998). In other words, by shifting the

grating pitch toward a longer wavelength, the wavelength reflected by the grating (reflective peak wavelength) can be shifted toward a longer wavelength.

In the case where the tensile force is applied after writing the grating, however, strain of the tensile side is caused, and hence, although the written grating pitch can be shifted toward a longer wavelength for controlling the wavelength characteristic, there arises a critical problem that the written grating pitch cannot be controlled to be shifted toward a shorter wavelength.

Moreover, in the method of shifting the wavelength characteristic toward a longer wavelength, it is necessary to fix the state where the tensile strain remains in the fiber grating by using, for example, adhering or fixing means in order to keep the wavelength shift, which restricts the structures of apparatuses employed in the aforementioned various uses.

In addition, it is necessary to apply the tensile force by means or a method not damaging the optical fiber as well as by means or a method not for testing facility but capable of mass production.

Furthermore, in writing the grating through the UV irradiation, refractive index modulation fringes are generated by causing photo-induced refractive index change in the core of the optical fiber through the UV irradiation. Therefore, in the optical fiber irradiated with UV, the coat layer in a portion irradiated with UV is generally removed from the viewpoint of

causing effective photo-induced refractive index change in the core. Accordingly, in the conventional method in which a grating is written in a non-coated fiber including a core and a cladding bearing no coat layer thereon and a tensile force is applied after the writing, it is necessary to set the upper limit of the applied tensile force to a tension value (tension load value) sufficiently small to avoid possibility of fracture of the non-coated fiber. Since the non-coated fiber is generally broken when the expansion exceeds approximately 1%, the applied tensile force is limited to a low tension range where the expansion is smaller than 1%. As a result, the shift toward a longer wavelength can be small in accordance with the small tensile force. The tension load value corresponding to the expansion of 1% is approximately 1 kg in a general non-coated fiber, and it is reported on this point in the paper on the method for applying the tensile force after writing the grating that the shift of the wavelength is as small as 5.4 nm in applying a tensile force of 0.5 kg. It is also described that the wavelength shift increases substantially in proportion to the increase of the tension load value.

In general fabrication of optical fibers, the fabricated optical fibers are generally subjected to a screening test for the mechanical characteristic. In fabrication of fiber gratings, however, although a test method for the transmitting performance such as a wavelength characteristic has been almost settled, a test method for a mechanical characteristic such as strength has

not been settled yet. Fiber gratings fabricated by using a fiber grating fabrication apparatus equipped with a UV irradiation system or the like can be possibly subjected to a screening test using a screening tester used for general optical fibers. In this case, however, the fabrication of fiber gratings and the screening test are independently carried out, which makes the process and work troublesome.

According to the invention described below, the wavelength characteristic can be controlled to be shifted toward a shorter wavelength by using a method for applying a tensile force. In addition, a large tensile force can be applied so as to increase the shift of the wavelength characteristic, the controllable range of the wavelength characteristic can be enlarged, the test for the mechanical characteristic by the screening test can be conducted after the fabrication of a fiber grating by using the same fabrication apparatus in continuous procedures, and a fiber grating fabrication apparatus utilizing shift of the wavelength characteristic (wavelength control) suitable for mass production can be provided.

Now, an embodiment of the invention will be described on the basis of the accompanying drawings.

First, a fiber grating fabrication apparatus capable of shift control of the wavelength characteristic using a coated fiber will be described with reference to Figure 18. The writing of a grating through UV irradiation can be conducted any of

various known methods. Figure 18 exemplifies the case where it is written by the phase mask method.

In the fiber grating fabrication apparatus of Figure 18, a phase mask 5 in a grating shape is disposed on the immediate side of the coated fiber 1, and a Nd-YAG laser source 6 is used for irradiating the phase mask 5 with a coherent UV laser beam of, for example, 266 nm, that is, a frequency-quadrupled wavelength (4ω) of the laser source, with the laser beam converged by using a cylindrical lens system 7. In this manner, the UV laser beam transmits the phase mask 5 and a coat layer 4, so as to write the grating 21 in the core 2 by increasing the refractive index of a portion of a grating pitch corresponding to the grating pitch of the phase mask 5. In Figure 18, a reference numeral "8" denotes a beam expander for expanding the UV laser beam into a parallel beam, a reference numeral "9" denotes a slit with a small width for taking out a part with uniform power of the UV laser beam changed into the parallel beam, and a reference numeral "10" denotes a movable reflecting mirror movable along the fiber axial direction (shown with a dashed arrow) of the coated fiber 1.

The phase mask 5, the Nd-YAG laser source 6, the cylindrical lens system 7, the beam expander 8, the slit 9 and the movable reflecting mirror 10 together form a UV irradiation system. Also, a reference numeral "11" denotes an optical spectrum analyzer, a reference numeral "12" denotes an optical isolator and a reference numeral "13" denotes an optical coupler, all of which together

correspond to a part for testing the wavelength characteristic of a fabricated fiber grating.

In this embodiment, a tension applying mechanism 30 is additionally provided for applying a tensile force to the coated fiber 1 in the fiber axial direction. The tension applying mechanism 30 includes, as shown in detail in Figure 19, a frame 31 disposed so as to surround a UV irradiated portion of the coated fiber 1; a pair of arm members 32 and 33 projecting from both sides of the frame 31 in the fiber axial direction of the coated fiber 1; a pair of winding reels 34 and 35, serving as fixing means, supported at the tips of the arm members 32 and 33, respectively; and a motor 36 (shown in Figure 20) for driving the winding reel 35 disposed on one side along the fiber axial direction (on the right hand side in Figure 19).

The frame 31 is not specified in its shape or the like as far as it has an opening 311 for transmitting the UV laser beam at least in a portion behind the coated fiber 1 (an upper portion in Figure 19) and can support the pair of arm members 32 and 33. Each of the arm members 32 and 33 is in an L-shape, with one end fixed on the frame 31 and the other end connected to the winding reel 34 or 35. Each of the winding reels 34 and 35 includes a mandrel 341 or 351 corresponding to a winding reel main body and a pair of flange portions 342 or 352 provided on both sides of the mandrel. The winding reel 34 disposed on one side along the fiber axial direction (on the right hand side in Figure 19) is

connected rotatably around an axis Y provided on the arm member
33 in a direction perpendicular to the fiber axial direction,
while the winding reel 34 disposed on the other side along the
fiber axial direction (on the left hand side in Figure 19) is
5 fixed so as not to rotate relatively to the arm member 32. The
motor 36 is constructed from a pulse motor, whose output axis
is connected to the mandrel 351 directly or through a connection
member. The motor 36 forcedly rotates the mandrel 351 by
predetermined revolutions in response to a control signal supplied
10 from a controller not shown.

Next, a method of fabricating a fiber grating by using the
fiber grating fabrication apparatus will be described.

In the fabrication of a fiber grating, a tension application
process, an irradiation process, a tension release process and
15 a screening process are successively carried out. Specifically,
in the tension application process, the coated fiber 1 is set
in a linearly expanded state by respectively winding both end
portions, sandwiching a portion where the grating 21 is to be
written, of the coated fiber 1 around the circumferences of the
20 mandrels 341 and 351 of the winding reels 34 and 35 twice or three
times so as not to overlap the wound portions (as shown in Figure
20). In this manner, the coated fiber 1 is fixed on the
circumferences of the mandrels 341 and 351 so as not to move along
the fiber axial direction by frictional resistance between the
25 circumferences of the mandrels 341 and 351 of the winding reels

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34 and 35 and the outer face of the coated fiber 1. Next, the motor 36 is driven so as to forcibly rotate the mandrel 351 by the predetermined revolutions and keep the rotated state. Thus, the portion of the coated fiber 1 between the pair of mandrels 341 and 351 is forcibly extended along the fiber axial direction by a circumferential length of the mandrel 351 corresponding to the forced revolutions, namely, a tensile force is applied so as to cause elastic strain (expansion strain) of the tensile side in the core 2. Under this condition, the subsequent irradiation process is carried out.

In the irradiation process, the phase mask 5 is set on the portion of the coated fiber 1 where the grating 21 is to be written, and the UV laser beam emitted from the UV irradiation system irradiates the coated fiber 1 through the phase mask 5 over the range between one end of the phase mask 5 in the fiber axial direction and the other end thereof. The irradiating position of the UV laser beam is changed within the range along the fiber axial direction by moving the reflecting mirror 10 along the fiber axial direction. In this manner, the grating 21 with a grating pitch corresponding to the grating pitch of the phase grating 5 is written through the UV laser beam irradiation in the core 2 in which the expansion strain is caused.

After writing the grating 21 in the irradiation process, the tension release process is conducted, in which the motor 36 is reversely driven by the predetermined revolutions so that the

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coated fiber 1 can be returned to the original state prior to the application of the tensile force to be restored to a no-load state. In this manner, the expansion strain caused in the core 2 restores to the original state, namely, the core is shrunken, and the grating pitch of the written grating 21 is narrowed in accordance with the shrinkage. Therefore, the wavelength characteristic of the grating 21 is shifted toward a shorter wavelength correspondingly to the narrowed grating pitch.

Thus, the fabrication of a fiber grating itself is completed, but in this embodiment, the screening process is subsequently conducted. Specifically, in the screening process, the motor 36 of the tension applying mechanism 30 is driven so as to cause given expansion strain along the fiber axial direction in the fiber grating for a predetermined time period, thereby conducting a screening test for the mechanical strength characteristic. In this manner, a fiber grating with a defect is omitted from products, with merely fiber gratings free from a defect remaining as the products. Thus, in the fabrication of a fiber grating, the formation of the grating 21 whose wavelength characteristic is shift-controlled as well as the screening of the fiber grating including the grating 21 can be conducted by using the same fabrication apparatus in continuous procedures. Accordingly, fiber grating fabrication apparatus and method suitable for mass production of fiber gratings can be provided.

In the shift control of the wavelength characteristic toward

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a shorter wavelength realized through the tension application process, the irradiation process and the tension release process, the coat layer 4 is formed on the coated fiber 1 where the grating 21 is written, and therefore, the tensile force applied in the tension application process can be set to a much larger value than the case where the non-coated fiber 1' excluding the coat layer 4 is used. Accordingly, the irradiation process can be conducted under application of a large tensile force, namely, in the state where large expansion strain is caused in the core 2, and hence, the shrinkage of the core 2 attained in the tension release process, namely, the degree of narrowing the grating pitch, can be large. As a result, the shift of the wavelength characteristic toward a shorter wavelength of the fiber grating attained after the tension release process can be very large, and thus, the shift control toward a shorter wavelength can be carried out over a very large wavelength range.

In the actual shift control of the wavelength characteristic (wavelength control), the relationship between an applied tensile force and shift of the wavelength characteristic toward a shorter wavelength is previously obtained through a test, so that an applied tensile force corresponding to the shift of the wavelength desired to be controlled can be predetermined on the basis of the relationship, and the predetermined revolutions of the motor 36 can be decided so as to apply the predetermined tensile force to the coated fiber 1.

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In the fabrication of a fiber grating, the UV irradiation may be conducted as follows in order to write the grating 21 more definitely by the UV laser beam irradiation through the coat layer 4:

5 The UV laser beam irradiation is conducted at an irradiation energy density of approximately 1.5 kJ/cm^2 . Thus, in the UV laser beam irradiation through the coat layer 4, even when the coat layer 4 has a thickness as large as approximately $30 \text{ }\mu\text{m}$ or more, the UV laser beam can transmit the coat layer 4 so as to cause
10 the high refractive index modulation in the core 2, resulting in writing the grating 21 with high reflectance.

In addition, the coated fiber 1 where the grating is to be written is placed in the specific position relative to the beam pattern BP of the UV laser beam converged by the cylindrical
15 lens system 7 as shown in Figure 11, and is irradiated with the UV laser beam under this condition. The beam pattern BP is formed by converging the parallel beam having passed through the cylindrical lens system 7 toward the focal point F, and the coated fiber 1 is placed so that the entire coated fiber 1 can be disposed
20 within the beam pattern BP and that the outer face of the coat layer 4 of the coated fiber 1 can be internally in contact with the outer edge of the beam pattern BP. As far as such a positional relationship is satisfied, the coated fiber 1 can be placed in front of the focal point F as is shown with the solid line in
25 Figure 11 or behind the focal point F as is shown with the dashed

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line in Figure 11. For example, when the focal distance $L1$ is 100 mm, a coated fiber 1 with an outer diameter of 200 μm may be placed on the optical axis away from the focal point F by a distance $L2$ substantially corresponding to 2 mm. By placing the entire coated fiber 1 within the beam pattern BP , the entire coat layer 4 can be irradiated with the UV laser beam at a uniform irradiation energy density. Moreover, local damage (strength degradation) of the coat layer 4, which can be occasionally caused in placing the coated fiber 1 closer to the focal point F , can be prevented, and the coated fiber 1 can be irradiated in a position for attaining the highest irradiation energy density within the range for avoiding the strength degradation, resulting in shortening the time required for writing the grating.

In the aforementioned embodiment, the tensile force is applied by the tension applying mechanism by forcedly rotating one winding reel 35 by using the motor 36 with the winding reel 35 rotatably supported on the arm member 33, which does not limit the invention. The tensile force can be applied to the coated fiber 1 by constructing the apparatus as followings: Both the winding reels 34 and 35 are respectively fixed on the arm members 32 and 33 so as not to rotate, one end 331 of one arm member 33 is guided and supported on the frame 31 movably in the fiber axial direction as shown with a dashed line in Figure 19, and the arm member 33 is forcedly moved in the rightward direction in Figure 19 by using, for example, a combination of a transmitting mechanism

such as a rack and a pinion, and a motor, or an actuator such as a hydropneumatic cylinder.

As described above, Embodiment 3 of the invention realizes the shift control of the wavelength characteristic toward a shorter wavelength, which cannot be realized by the conventional tension applying method for keeping application of a tensile force after writing a grating. Also, the wavelength characteristic of a fiber grating can be stably shifted toward a shorter wavelength. In addition, as compared with the conventional tension applying method, there is no need to keep the tension application in the individual optical fiber where the grating has been written, and hence, a fiber grating easy to deal with and controlled in the wavelength by the tension application can be easily mass produced.

Furthermore, since a coated fiber bearing a coat layer is used as an optical fiber for fabricating a fiber grating, a much larger tensile force can be applied than in use of a non-coated fiber without a coat layer, and therefore, the shift of the wavelength characteristic toward a shorter wavelength can be increased, and the range of the wavelength control can be largely increased.

Moreover, since the screening process for conducting a screening test is continuously conducted by applying a predetermined tensile force to a portion where the grating has been written in the fabricated fiber grating, a test for the mechanical characteristic of the portion where the grating has

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been written with the wavelength controlled, namely, a test for the strength and surface damage, can be carried out following the fabrication of the fiber grating. Thus, a suitable mass production system for fiber gratings with the wavelength control is provided. Furthermore, according to the fiber grating fabrication apparatus of this invention, even when the irradiation process and the screening process alone are conducted, the writing of a grating and the screening test of the fiber grating where the grating has been written can be carried out by using the same fabrication apparatus.

Industrial Applicability

The present invention provides a fiber grating (including a short-period fiber grating and a long-period fiber grating) in which a grating can be easily written without causing degradation of the transmitting characteristic. Also, the invention stabilizes not only the transmitting characteristic but also the temperature characteristic, so as to provide a highly reliable fiber grating. Accordingly, the transmitting characteristic and the mechanical strength characteristic can be improved without spoiling the improvement of productivity.

CLAIMS

1. A fiber grating comprising a core where a grating is written, a cladding for covering the core, and a coat layer for coating an outer face of the cladding,

5 wherein the coat layer is made from a UV transmitting resin and has a characteristic of transmitting UV at least of a specific wavelength band used for writing the grating and of curing by absorbing UV of a shorter wavelength band or a longer wavelength band than the specific wavelength band, and

10 the grating is written by irradiating the core with the UV of the specific wavelength band through the coat layer.

2. The fiber grating of Claim 1,

wherein the core is co-doped with Ge and Sn, and

15 a concentration of Ge is substantially the same as a concentration of Ge included in a core of another optical fiber to be connected to the fiber grating.

3. The fiber grating of Claim 1 or 2, further comprising a secondary coat layer for coating an outer face of the coat layer,

20 wherein the secondary coat layer is made from a material having a negative coefficient of linear expansion.

4. The fiber grating of Claim 1,

wherein the coat layer is formed from a single coat film with a thickness of 30 μm or more.

5. The fiber grating of Claim 2,

25 wherein the core is further doped with Al.

6. A method of fabricating a fiber grating comprising the steps of:

fabricating a glass fiber structure including a core where a grating is to be written and a cladding for covering the core;

coating an outer face of the glass fiber structure with a coat layer of a UV transmitting resin; and

writing the grating in the core by irradiating the core with UV through the coat layer,

wherein the coat layer has a large thickness for attaining a mechanical strength characteristic equivalent to that of a coated fiber to be connected to the fiber grating, and

the UV is obtained by using solid laser and irradiates the core at an irradiation energy density within a range between 1.5 and 4.0 kJ/cm².

7. The method of fabricating a fiber grating of Claim 6, wherein the UV has a wavelength of 250 nm through 350 nm.

8. The method of fabricating a fiber grating of Claim 6 or 7,

wherein the coat layer is formed by a single coating method in a thickness of 30 μ m through 50 μ m.

9. The method of fabricating a fiber grating of Claim 6 or 7,

wherein the step of writing the grating includes steps of:

placing all the coat layer, the cladding and the core in a position between a cylindrical lens and a focal point of

the cylindrical lens and within a beam pattern of the UV converged toward the focal point by the cylindrical lens; and

irradiating the core with the UV through the cylindrical lens.

5 10. The method of fabricating a fiber grating of Claim 6, wherein, in the step of writing the grating, an outer face of the coat layer is internally in contact with an outer edge of a beam pattern of the UV.

10 11. The method of fabricating a fiber grating of Claim 6, wherein the core is loaded with hydrogen before irradiating with the UV.

12. The method of fabricating a fiber grating of Claim 6, wherein the core is co-doped with Ge and Sn.

15 13. A method of fabricating a fiber grating comprising: a tension application step of causing tensile strain along a fiber axial direction by previously applying a tensile force along the fiber axial direction to a grating write portion of an optical fiber to be fabricated into a fiber grating;

an irradiation step of writing the grating with a
20 predetermined grating pitch along the fiber axial direction in a core of the optical fiber by irradiating the optical fiber with UV with keeping the tensile force applied in the tension application step; and

a tension release step of shifting the grating pitch of
25 the grating written in the core toward a shorter wavelength by

releasing application of the tensile force after the irradiation step.

14. The method of fabricating a fiber grating of Claim 13, wherein the optical fiber is a coated fiber obtained by coating a non-coated fiber including the core and a cladding with a coat layer of a UV transmitting resin.

15. The method of fabricating a fiber grating of Claim 13, further comprising a screening step of conducting a screening test on the grating write portion by applying a predetermined tensile force to the optical fiber after the tension release step.

16. A method of fabricating a fiber grating, by using a fiber grating fabrication apparatus including a UV irradiation system for irradiating, with UV, an optical fiber to be fabricated into a fiber grating and a tension applying mechanism for applying a tensile force in a fiber axial direction to the optical fiber, comprising:

an irradiation step of writing a grating along the fiber axial direction in a core of the optical fiber by irradiating the optical fiber with UV by using the UV irradiation system; and

a screening step of conducting a screening test on a portion where the grating has been written by applying a predetermined tensile force to the optical fiber by using the tension applying mechanism after the irradiation step.

17. A fiber grating fabrication apparatus comprising:

a UV irradiation system for writing a grating with a predetermined grating pitch along a fiber axial direction in a core of an optical fiber to be fabricated into a fiber grating by irradiating the optical fiber with UV; and

5 a tension applying mechanism for causing tensile strain along the fiber axial direction by temporarily applying a tensile force to a portion of the optical fiber irradiated with UV by the UV irradiation system.

18. The fiber grating fabrication apparatus of Claim 17,
10 wherein the tension applying mechanism includes:

a pair of fixing means for respectively fixing two portions of the optical fiber away from each other along the fiber axial direction and sandwiching the portion of the optical fiber irradiated with UV by the UV irradiation system; and

15 moving means for forcedly moving at least one of the pair of fixing means along the fiber axial direction away from and toward the other of the pair of fixing means.

19. The fiber grating fabrication apparatus of Claim 18,
wherein the pair of fixing means are winding reels each
20 for fixing the optical fiber, with frictional resistance against the optical fiber, by winding the optical fiber around an axis thereof perpendicular to the fiber axial direction, one of the winding reels to be moved by the moving means being rotatably supported around the perpendicular axis in one position along
25 the fiber axial direction, and

the moving means is a motor for forcedly rotating one of the winding reels to be moved by predetermined revolutions with the optical fiber wound.

Abstract

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A core 2 is co-doped with Ge in a general concentration equivalent to that in a core of an optical fiber to be connected as well as Sn and Al in predetermined concentrations. A glass part F including the core and a cladding 3 is coated with a primary coat layer 4 of a UV transmitting resin which transmits UV of 240 nm through 270 nm but cures by absorbing UV of a shorter wavelength band than 240 nm or a longer wavelength band than 270 nm. A grating is written in the core by irradiating the core with UV through the primary coat layer. The primary coat layer is covered with a secondary coat layer 7 of a resin having a negative coefficient of linear expansion so as to cancel and suppress expansion/shrinkage of the glass part in accordance with temperature change derived from the positive coefficient of linear expansion. Thus, the invention provides a fiber grating and a method of fabricating a fiber grating, in which a grating can be easily written without causing degradation of the transmitting characteristic, the transmitting characteristic and the mechanical strength characteristic can be consistent with each other without spoiling improvement of productivity, and the temperature characteristic can be stabilized for attaining high reliability.

FIG. 1

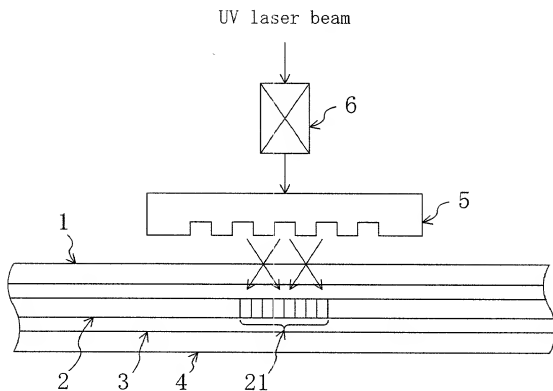
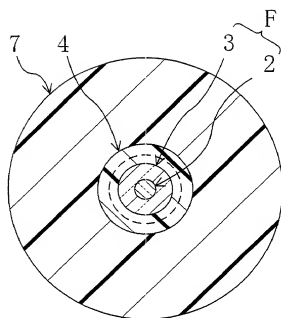


FIG. 2



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FIG. 3

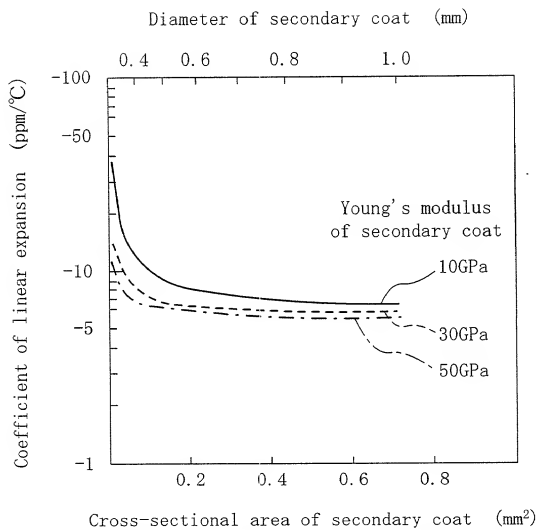


FIG. 4

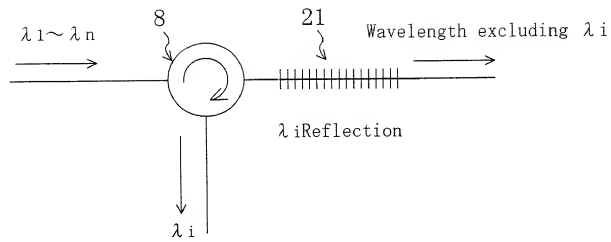


FIG. 5

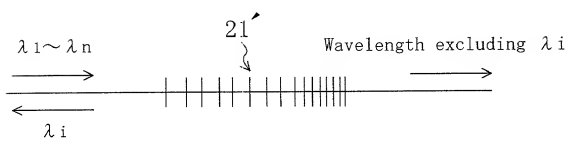
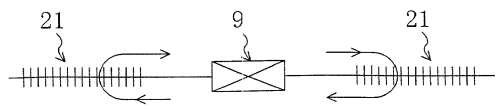


FIG. 6



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FIG. 7

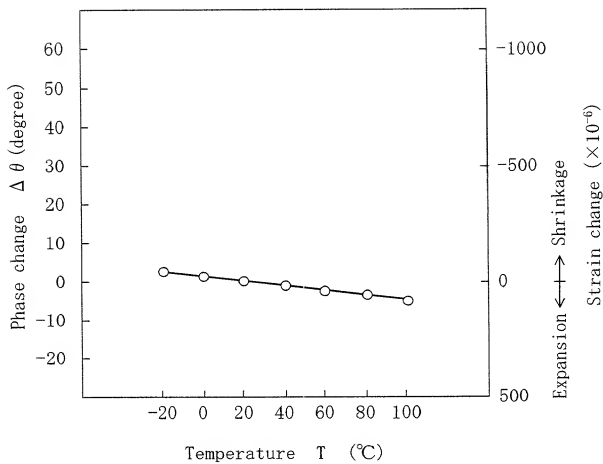


FIG. 8

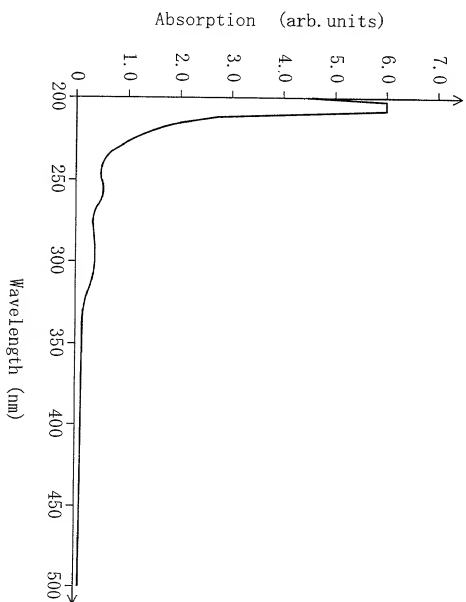
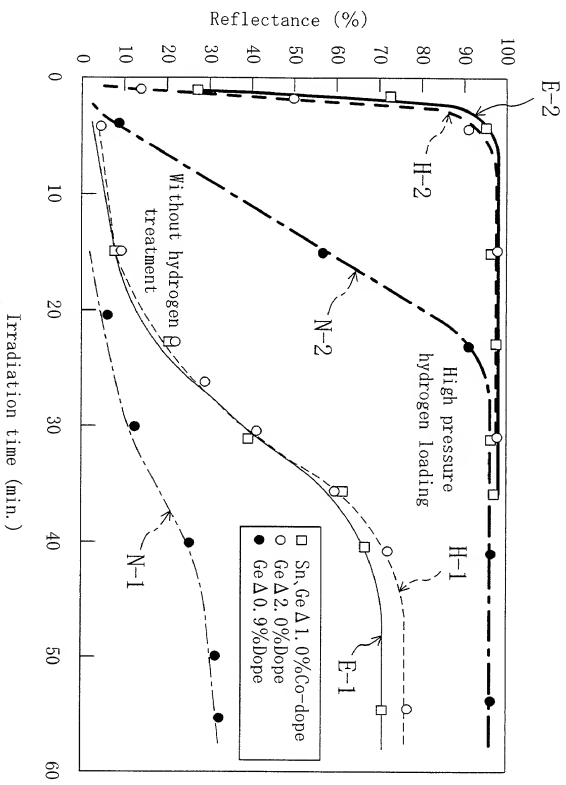


FIG. 9



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FIG. 10

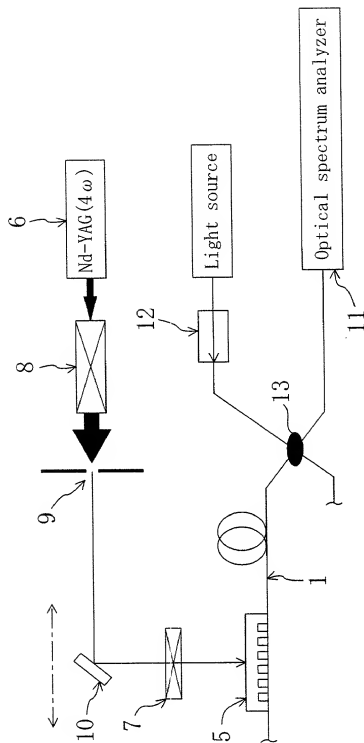
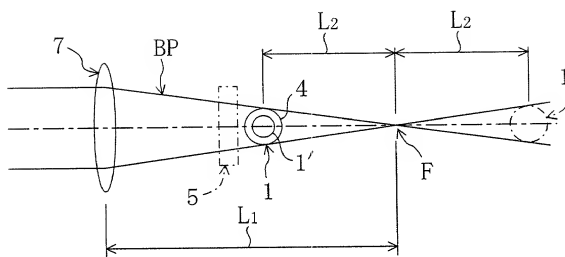
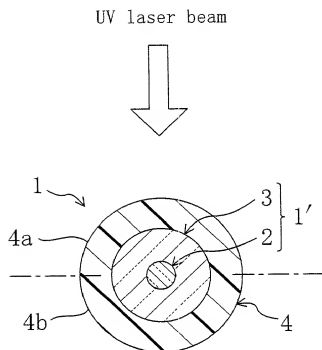


FIG. 11



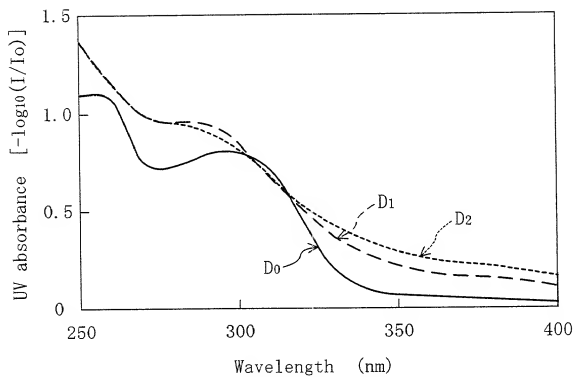
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FIG. 12



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FIG. 13



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FIG. 14

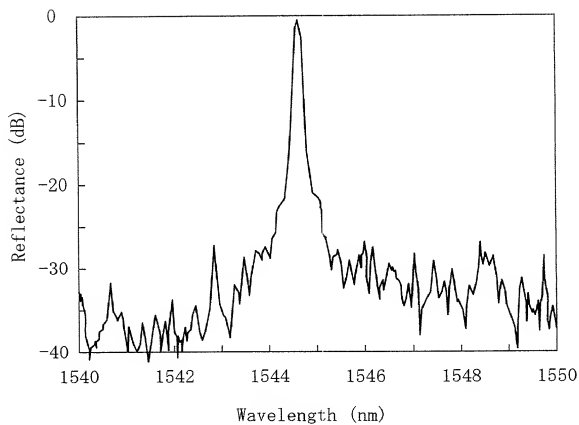


FIG. 15

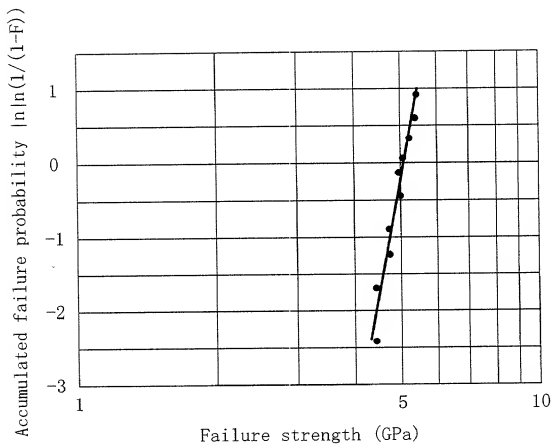


FIG. 16

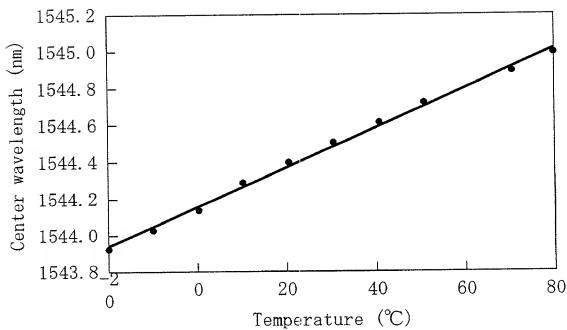


FIG. 17

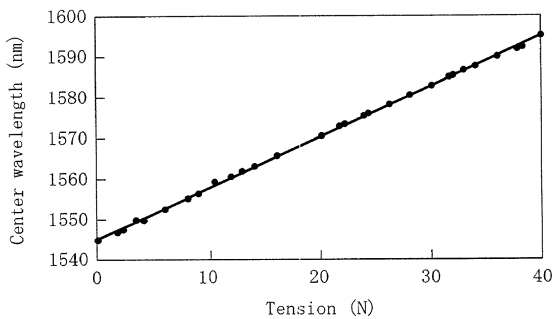
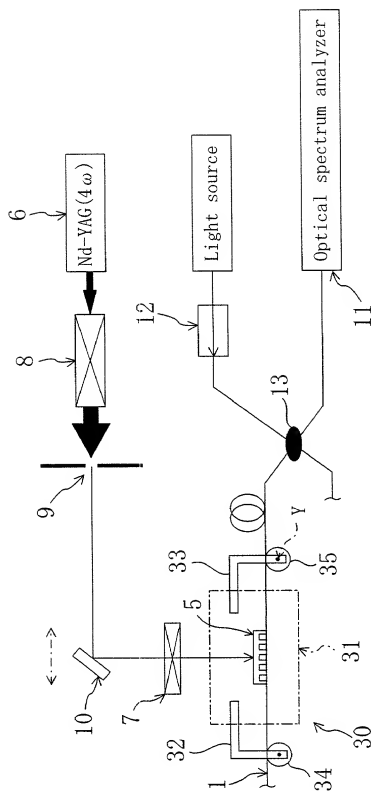


FIG. 18



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FIG. 19

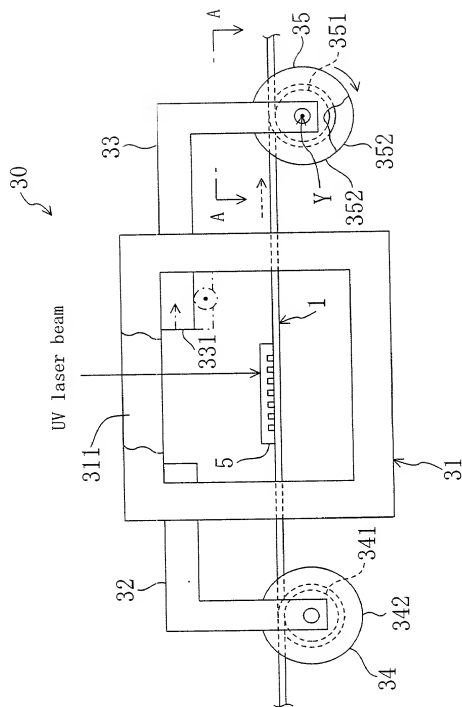
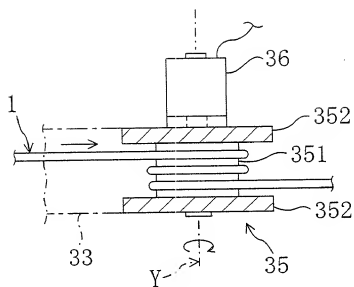


FIG. 20



COMBINED DECLARATION FOR PATENT APPLICATION AND POWER OF ATTORNEY

(Includes Reference to PCT International Applications)

Attorney Docket No:

As a below named inventor, I hereby declare that:

My residence post office address and citizenship are as stated below next to my name,

I believe I am the original, first and sole inventor (if only one name is listed below) or an original, first and joint inventor (if plural names are listed below) of the subject matter which is claimed and for which a patent is sought on the invention entitled:

FIBER GRATING AND METHOD AND APPARATUS FOR FABRICATING THE SAME

the specification of which (check only one item below):

☐ is attached hereto.

☐ was filed as United States application

Serial No. _____
on _____
and was amended
on _____ (if applicable).

☒ was filed as PCT international application

Number PCT/JP98/05311
on November 25, 1998
and was amended under PCT Article 19
on _____ (if applicable).

I hereby state that I have reviewed and understand the contents of the above-identified specification, including the claims, as amended by any amendment referred to above.

I acknowledge the duty to disclose information which is material to the examination of this application in accordance with Title 37, Code of Federal Regulations. §1.56.

I hereby claim foreign priority benefits under Title 35, United States Code, §119 of any foreign application(s) for patent or inventor's certificate or of any PCT international application(s) designating at least one country other than the United States of America listed below and have also identified below any foreign application(s) for patent or inventor's certificate or any PCT international application(s) designating at least one country other than the United States of America filed by me on the same subject matter having a filing date before that of the application(s) of which priority is claimed:

PRIOR FOREIGN/PCT APPLICATION(S) AND ANY PRIORITY CLAIMS UNDER 35 U.S.C. 119:

COUNTRY	APPLICATION NUMBER	DATE OF FILING (day, month, year)	PRIORITY CLAIMED UNDER 35 USC 119
Japan	9-324167	26/11/1997	<input checked="" type="checkbox"/> YES <input type="checkbox"/> NO
Japan	10-112259	22/04/1998	<input checked="" type="checkbox"/> YES <input type="checkbox"/> NO
Japan	10-203077	17/07/1998	<input checked="" type="checkbox"/> YES <input type="checkbox"/> NO
			<input type="checkbox"/> YES <input type="checkbox"/> NO
			<input type="checkbox"/> YES <input type="checkbox"/> NO

COMBINED DECLARATION FOR PATENT APPLICATION AND POWER OF ATTORNEY <small>(Includes Reference to PCT International Applications)</small>			Attorney Docket No:	
<p>I hereby claim the benefit under Title 35, United States Code, §119(e) or §120, as applicable of any United States application(s) or PCT international application(s) designating the United States of America that is/are listed below and, insofar as the subject matter of each of the claims of this application is not disclosed in that/those prior application(s) in the manner provided by the first paragraph of Title 35, United States Code, §112, I acknowledge the duty to disclose material information as defined in Title 37, Code of Federal Regulations, §1.56 which occurred between the filing date of the prior application(s) and the national or PCT international filing date of this application:</p>				
PRIOR U.S. APPLICATIONS OR PCT INTERNATIONAL APPLICATIONS DESIGNATING THE U.S. FOR BENEFIT UNDER 35 U.S.C. 120:				
U.S. APPLICATIONS			STATUS (Check one)	
U.S. APPLICATION NUMBER	U.S. FILING DATE	PATENTED	PENDING	ABANDONED
PCT APPLICATIONS DESIGNATING THE U.S.				
PCT APPLICATION NO.	PCT FILING DATE	U.S. SERIAL NUMBERS <small>ASSIGNED (if any)</small>		
<p>POWER OF ATTORNEY: As a named inventor, I hereby appoint the following attorney(s) and/or agent(s) to prosecute this application and transact all business in the Patent and Trademark Office connected therewith. <i>(List name and registration number)</i></p>				
<div style="display: flex; justify-content: space-between;"> <div style="width: 45%;"> Daniel W. Sixbey, (Reg. No. <u>20,932</u>) Charles M. Leedom, Jr. (Reg. No. <u>26,477</u>) David S. Safran (Reg. No. <u>27,997</u>) Donald R. Studebaker (Reg. No. <u>32,815</u>) Tim L. Brackett (Reg. No. <u>36,092</u>) Frank P. Presta (Reg. No. <u>19,828</u>) Robert M. Schulman (Reg. No. <u>31,196</u>) Lawrence D. Eisen (Reg. No. <u>41,009</u>) </div> <div style="width: 45%;"> Stuart J. Friedman (Reg. No. <u>24,312</u>) Gerald J. Ferguson, Jr. (Reg. No. <u>23,016</u>) Thomas W. Cole (Reg. No. <u>28,290</u>) Jeffrey L. Costellia (Reg. No. <u>35,483</u>) Eric J. Robinson (Reg. No. <u>38,285</u>) Joseph S. Presta (Reg. No. <u>35,329</u>) Thomas M. Blasey (Reg. No. <u>33,475</u>) </div> </div>				
Send Correspondence to: <u>SIXBEY, FRIEDMAN, LEEDOM & FERGUSON, P.C.</u> <u>8180 Greensboro Drive, Suite 800</u> <u>McLean, Virginia 22102</u>			Direct Telephone Calls to: <i>(name and telephone number)</i> Gerald J. Ferguson, Jr. (703) 790-9110	
<p>I hereby declare that all statements made herein of my own knowledge are true and that all statements made on information and belief are believed to be true; and further that these statements were made with the knowledge that willful false statements and the like so made are punishable by fine or imprisonment, or both, under Section 1001 of Title 18 of the United States Code and that such willful false statements may jeopardize the validity of the application or any patent issued thereon.</p>				
<p>The undersigned hereby authorize any U.S. attorney or agent named herein to accept and follow instructions from <u>MAEDA PATENT OFFICE</u> as to any action to be taken in the Patent and Trademark Office regarding this application without direct communication between the U.S. attorney or agent and the undersigned. In the event of a change in the persons from whom instructions may be taken, the U.S. attorneys or agents named herein will be so notified by the undersigned.</p>				
FULL NAME OF SOLE OR FIRST INVENTOR Kazuo IMAMURA		INVENTOR'S SIGNATURE 		DATE May 23, 2000
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2- FULL NAME OF SECOND JOINT INVENTOR (if any) Tadahiko NAKAI	INVENTOR'S SIGNATURE <i>T. Nakai</i>	DATE May 23, 2000
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3- FULL NAME OF THIRD JOINT INVENTOR (if any) Yasuhide SUDO	INVENTOR'S SIGNATURE <i>Y. Sudo</i>	DATE May 23, 2000
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FULL NAME OF FOURTH JOINT INVENTOR (if any)	INVENTOR'S SIGNATURE	DATE
RESIDENCE (City, State & Country)		CITIZENSHIP
POST OFFICE ADDRESS (Complete Address including City, State & Country)		
FULL NAME OF FIFTH JOINT INVENTOR (if any)	INVENTOR'S SIGNATURE	DATE
RESIDENCE (City, State & Country)		CITIZENSHIP
POST OFFICE ADDRESS (Complete Address including City, State & Country)		
FULL NAME OF SIXTH JOINT INVENTOR (if any)	INVENTOR'S SIGNATURE	DATE
RESIDENCE (City, State & Country)		CITIZENSHIP
POST OFFICE ADDRESS (Complete Address including City, State & Country)		
FULL NAME OF SEVENTH JOINT INVENTOR (if any)	INVENTOR'S SIGNATURE	DATE
RESIDENCE (City, State & Country)		CITIZENSHIP
POST OFFICE ADDRESS (Complete Address including City, State & Country)		
FULL NAME OF EIGHTH JOINT INVENTOR (if any)	INVENTOR'S SIGNATURE	DATE
RESIDENCE (City, State & Country)		CITIZENSHIP
POST OFFICE ADDRESS (Complete Address including City, State & Country)		